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PREFACE

TO

THE FRENCH EDITION.

SCIENCE in the present day pursues a double object, for not satisfied with enlarging the bounds of our knowledge in all directions, it also adds continually by its discoveries to the welfare of the world at large.

Amongst the results which have been obtained by science in this respect we ought to place in the first rank the discovery of the laws which regulate the lives of the people and determine the conditions of their existence. In this way science has thrown a strong light on the intimate connection which exists between the population and its system of agriculture, a matter which is easy of explanation, seeing that plants spring from the soil, that animals live on these plants, and that man feeds on both.

Formerly the whole principles of agriculture were reduced to a single rule, which was accepted as an axiom and entered as such into the farmer's daily practice. Divide the land into two nearly equal parts, set one aside for grazing purposes or for growing forage plants, and reserve the other for cereal crops. From this axiom was deduced the following formula, which became in some sort sacramental: in order to grow cereals there must be meadow land, cattle and manure.

But science, by revealing to us the nature of the constituents of which plants are formed, has proved most conclusively that this maxim was directly antagonistic to the result at which the farmer proposed to arrive; that it led irrevocably to the exhaustion of the soil to such an extent, that if its teachings were rigorously carried out, agriculture would not

have satisfied the wants which have sprung from the increase of the population.

I repeat that the farmer who uses nothing but farmyard manure infallibly exhausts his land, for the manure has the soil for its source, and if he only diminishes the loss which the soil has suffered he cannot in the end repair it. When cattle are exported the loss is not so great as when grain is sold, but still there is always a certain amount of loss. Therefore this axiom, which has hitherto formed the basis, and as it were the supreme law of farming, is in reality nothing more than an expedient.

It must also be remarked that with farm manure only it is impossible to obtain maximum crops, which are alone remunerative. We must not therefore deceive ourselves; the traditions of the past are not sufficient for the necessities of the present. We want more rapid, more economical and more powerful processes. These processes, however, are already discovered and are described in a single maxim: give back to the soil by the permanent importation of chemical manure an amount of fertilising material larger than that lost by the growth of the crops. Thanks to these new fertilising agents, instead of being still obliged to grow meat in order to have corn, we may now grow corn for profit's sake in the first place, and afterwards for straw, cattle-feeding and manure.

When farmyard manure only is used, the improvement of the land requires length of time and an enormous outlay of capital. With chemical manures the result is more rapidly arrived at. We may almost immediately obtain large crops from the most barren lands, and realise a profit at the very outset.

This is reversing the order of things practised and recognised up to the present time. But it may be asked, is it really certain that the new agents which science has discovered for us possess the sovereign properties attributed to them? Without anticipating the proofs, which I intend adducing further on, I will mention a single example, which is so significant that it must needs be satisfactory.

M. Ponsard, President of the Agricultural Committee of d'Omey, in Champagne, made two parallel experiments on a

piece of waste land in one of the most barren districts of a proverbially barren portion of that province. He manured one-half of the ground with about 32 tons of farmyard manure per acre, and the other with about half a ton of chemical manure per acre. With the farm manure he obtained about 14 bushels of wheat, whereas with the chemical manure the land yielded about 36 bushels, there being a loss of 19*l.* in the former case, and a gain of 17*l.* in the latter.

It may be objected that the farmyard manure had not exhausted its action in a single year, whereas the chemical manure had done so. I can only reply that this idea is contrary to all the known facts. Let us, however, admit it; the result will not be less striking. The worst that could happen would be that the field would have to be manured afresh in order to grow a new crop, but the first result furnishes us with the means.

By the aid of these new methods of cultivation, agriculture then acquires a liberty of action formerly unknown. There need be no longer any question of wearisome delays, of the enormous expenses which are attached to farming, founded on cattle-feeding; there need be no more expensive buildings, nor sinking of capital for lengthened periods. As M. Leconteux has said with great justice, the farmer may sink and regain his capital year by year.

But here certain questions present themselves to our consideration, on the solution of which depends the triumph of the new system. Whence are we to draw our supply of those agents, which according to our present ideas, are destined to become the principal lever of agriculture? How are we to use them? What results can be obtained in practice? These are, in fact, the subjects of which we shall treat in the present work.

These materials exist as inexhaustible deposits in the bowels of the earth, where they have lain for thousands of years, and where a watchful Providence seems to have kept them in reserve, to counteract the improvidence of the past and to preserve us from its inevitable consequences.

But if these products, of whose value we can have no doubt, are at hand in inexhaustible quantities, it is evident that as their use becomes more general, they will, by increasing

the fertility of the land, improve our conditions of existence, and give a most powerful impetus to the increase of the population.

The end which we should endeavour to attain is to some extent obligatory on us. Private initiative, agreeing on this point with the interests of the community, ought to try its utmost to alter the economy of our agricultural system. On this condition, and on this condition only, shall we be able to see a revival of prosperity in our agricultural districts which will make itself felt amongst all classes of the people.

Nature has greatly favoured us. Situated as we are between two seas, we have the advantage of rapid communication with the two extremities of Europe, and possess besides a more favourable climate than that of any other country. Notwithstanding this, what is our agricultural position? It requires some courage to acknowledge it: we find ourselves in a notoriously inferior position with regard to other nations.

The average yield of wheat in France is about 15 bushels per acre, but under the present system the cost of growing corn is about 5s. 6d. per bushel, a price which it is easy to reduce to about 3s. 9d. per bushel. It must also be observed that if the ordinary average rises to 15 bushels, we have to thank eight or ten of our northern departments which yield an average of about 33 bushels. If these were taken away the mean would fall to not more than 11 bushels. What can be the position of a country whose agriculture is in such a precarious state? What is our true situation? The falling off in the increase of our population will answer this question.

The population of France as given in the *Moniteur* of 19th January, 1867, including Nice and Savoy, was 38,067,000, having increased by 680,333 during the preceding quinquennial period. According to these data the period at which the population doubles itself in France is 131 years; for Prussia it is 69 years; for Russia it is 50 years; for England 47 years; and for America only 25 years. In 1820 we were one of the first Powers in Europe as far as population went; in twenty or thirty years we shall be one of the smallest in this respect.

One thing has always surprised me, and that is that

historians and statesmen have inquired so little into the conditions which govern the life of the people, and which cause it to be exuberant and full of vigour in one place, and languishing and weak in another.

One department in a State is dependent on the other ; for instance, commerce, agriculture and increase of population.

Of these three forms in which social activity manifests itself, agriculture is by far the most important, whether by the capital it represents, the revenue it creates, or the preponderating influence it exercises on the well-being of the country. If we draw a comparison between the progress made by manufactures and by agriculture, we shall be puzzled at finding how much the last-named industry has remained behind. If we wished to quote examples, it would be easy to show that since the beginning of the century different branches of manufacture have increased their powers of production tenfold, while agricultural produce has barely doubled. Why should so much progress have been made in one case and so little in the other ? The answer is ready. When we replace manual labour by machinery, the progress which it is possible to make in any branch of manufacture has scarcely any limit ; but when we come to the cultivation of the soil, the conditions are no longer the same. Increase in production depends less on the worker and on the quality of the tools which he employs than upon the quantity of fertilising materials which he has at his disposal. When, therefore, he has, so to speak, to draw out of his capital both his manure and the products which he exports, he soon comes to a limit beyond which it is impossible to go. He can only obtain precarious yields. I repeat that to prolong this state of things indefinitely is in the present day inexcusable, because we know how to remedy it.

The necessity which is imposed on the farmer is not to produce manure, but to manure his field more abundantly than formerly, no matter what may be the material he employs, whether it be farmyard manure or chemical manures, used either together or separately.

At a period when the means of communication had not reached the development which they have since acquired, the home markets provided certain and easy outlets for

agricultural produce. But at the present time, with free trade and the facilities of transport, farmers are compelled to compete in our own markets with all the world. In order that the struggle may be possible and remunerative, it is absolutely necessary that crops of every kind should be increased to their utmost possible limit. Under the old system this result was impossible, except, indeed, the whole of our agricultural system itself had been remodelled or changed, which could not have been effected; with chemical manures the case is altered, resolving itself simply into a small investment of capital.

Here I anticipate a fresh objection. It will be said that from an economical, legislative and financial point of view the position in which agriculture is placed offers an insurmountable obstacle to the application of new methods. We must, I fear, allow that if on one side everything has been accomplished, on the other everything or nearly everything remains to be done. But is the evil irremediable? Far from it, and it lies with the farmers to put a stop to it when they wish.

The inquiry, which has been so unsatisfactory from so many standpoints, will have had at least an excellent result—that of having thrown a light on the changes in our legislation which are absolutely necessary, as well as having indicated the agricultural institutions which should be founded without further delay.

In the first place, the whole agricultural community were unanimous in asking that the benefits of the credit system should be extended to farming, that it should enjoy the same privileges in this respect as other branches of industry, and that, to that end, the 2102nd Article of the Code Napoléon should be abrogated, or at any rate amended in a liberal spirit.

According to the terms of this article everything belonging to a farm, as well as the farm produce, is vested in the hands of the head landlord as a security for any rent which is or which may be unpaid at the time being; so that the tenant can dispose of nothing. It follows from this that a farmer possessing a lease and plant worth 4,000*l.* cannot obtain credit, having no security to offer; hence he cannot raise money for necessary improvements.

The last paragraph of the 2102nd Article allows an exception. It says: "The sums due for the harvest expenses of the year are paid out of the price of the harvest, those due for tools out of the price of the tools, preferably to the landlord in both cases".

This exception is insufficient. Everything that tends to improve the condition of the soil, everything which increases the yield of the land, adds really to the value of the property, and consequently has the right to the same privileges as the landlord. In the category of privileged debts we must include the purchase of cattle, and especially the money laid out for improvements and manure. May I be allowed to insist on giving the preference to expenses of the last-mentioned description, because the advantages connected with them are more immediate and better known to me. It is, besides, well known that these enactments already exist in England and Scotland, and that all classes are satisfied with them, both landlords and farmers.

Every farmer who cultivates a piece of land capable of yielding about 14 bushels per acre may, by expending from say 30s. to 50s. per acre on manure, double the yield, or increase the value of each acre by about 4*l.* 16s.

Is it right that whoever has advanced the price of the manure should have no resource, no lien on the crops which he has doubled, but should have to give place to the landlord?

When we think of the benefit which would accrue to the country at large by the more general use of a larger quantity of chemical manure, it is difficult to understand why no legislative measures have been brought in to place the system of purchasing manure on a solid basis, the payment not to become due until after the harvest has been gathered.¹

Another reform, which is not less urgent, is the reduction or abolition of the taxes payable on the transfer of property from one tenant to another by purchase, which is excessive in France. The base of the tax is $5\frac{1}{2}$ per cent. with a $\frac{1}{10}$ over, and this makes a little more than 6 per cent., and with the $\frac{2}{10}$ at the present time collected, it amounts to rather more than $6\frac{1}{2}$ per cent. Such a tax interferes greatly with these

¹ See a lecture given by me on the agricultural crisis, at the Sorbonne in 1865, p. 24.

transactions. If it were reduced within reasonable limits, so that neither buyers nor sellers would be aggrieved by it, landed property would change hands with the greatest ease, and would be more likely to pass into the hands of persons who had greater aptitude for working it profitably. In England this tax only amounts to $1\frac{1}{2}$ per cent.

We have, however, at least, the satisfaction of stating that a project will shortly be laid before the Corps Legislatif for amending these portions of the law.

If in these days there is one truth more elementary than another with regard to the connection between the riches of private individuals and the property of the State, it is that every industry requires the help of capital to make it productive. The want of capital is one of the principal causes which has retarded the progress of agriculture amongst us. It is not that, since 1789, our legislators have failed to seek in various ways the best means of putting capital at the disposal of the farmer, but that they have never succeeded. In 1856, and again in 1860, this defect was tried to be remedied, but the *Crédit Foncier* could not furnish the farmer with the capital that he required, and the *Crédit Agricole*, whose action was paralysed by Article 2102, has, as yet, only served to discount the bills received from those to whom it lends on security.¹

To these serious causes of inferiority we must add another, against which M. Michel Chevalier protested with equal authority and eloquence while acting as President of the Commission of the International Exhibition of 1867; we mean the state of ignorance in which our rural population is allowed to remain. "I do not hesitate to affirm," said this eminent economist, "that in our country districts, amongst the male population between the ages of thirty and fifty, not a single person can read and write, whilst amongst the females we should not find more than one in twenty. A population under such conditions is outside the pale of civilised life, and except we indulge in chimerical dreams, we are in no way authorised to count upon them as being likely to make any great progress in agriculture, or to contribute towards a rapid increase in the public riches or the resources of the State."

¹ See on this subject two excellent pamphlets by M. Rivet.

As the finishing stroke to this sad picture we may add that our country cross-roads are not equal to our wants; that railway lines are not sufficiently numerous; that their rates are too high; that our canals are too shallow; and that the work of completing our great arteries of communication is continually being deferred.

Besides these reforms, there is also great need for inquiring into the means of stopping the too great subdivision of land, which has been brought about by the law of succession, which our manners and customs lead us to preserve.

This is a problem which has already been considered by the powers that be; and seeing what has been done in this respect in foreign countries, its solution ought not to be impossible. The consideration of this question would be to raise a controversy which would touch our whole social organisation, for which reason I prefer to confine myself within the scope of the practical character of this book.

To sum up. The materials to which plants owe their formation, and the earth its fertility, being known, we may with their aid manufacture manures which are superior to that of the farmyard.

The march of progress and our own interest oblige us to make a more extensive and regular use of these materials. By so doing we shall increase the fertility of the soil and improve the condition of the people generally.

In order that the use of these materials may be possible in a general manner, four legislative reforms are indispensable; we must amend Article 2102 of the Code Napoléon, that the farmer may be able to use what he possesses to obtain the credit necessary for his business; the transfer tax must be lowered; the *Crédit Agricole* must be really established; and primary instruction must be more widely spread and better adapted to the wants of the agriculturalist. By unveiling the sources of plant production, science has done her work; it is now for the State, in conjunction with the farmer, to do theirs.

The above pages formed the introduction to the lectures delivered by me at Vincennes in 1867. When I go back to 1860, the date of my first field experiments at Vincennes, and remember the small number of auditors that then surrounded

me, most of them being personal friends desirous of supporting me by their presence, and compare them with the crowds which now flock to hear me; and when I further consider the importance of the results obtained by the increased application of chemical manures, I find at once the reward and the justification of the confidence which has always animated me.

I think I may also rely on my efforts being criticised with greater impartiality than on previous occasions. Formerly both the principles and the results of my work were altogether denied. Read the agricultural journals of ten years ago, and compare their articles with those of to-day. There has ceased to be any opposition to the basis of the doctrine; the new facts brought forward in 1867, facts which were then sneered at, having been verified by thousands of experiments, have now come to be accepted as demonstrated truths. There is only one point on which opposition still exists in some quarters, namely, the discoverer of the principles: the honour has been given successively to M. Boussingault, to German and to English *savants*, and finally wrested from all these, and the new doctrine of chemical manures considered as the work of no one man, but the fruit of general progress in science.

There is nothing surprising in this. What original work is there that has not been treated in the same manner? When we think that Lavoisier, one of the brightest and purest minds of our age, had this to contend with, we cease to wonder. But who now hears of Hassenfratz, of Baumé, or of Cadet-Gassicourt, whose opinions were then quoted in opposition to Lavoisier's, as if they had been his equals or rivals?

We must allow time to complete the work of justice, and give to every one his proper place, taking care on our own part to follow out the course of our studies patiently and laboriously, lending an attentive ear to all the discussions in agricultural matters both in France and in other countries. I never allow a well-founded objection to pass without a reply, and certainly one that has not its foundation in fact could never induce me to change my opinion.

But instead of allowing discussion to become personal disagreements, I have endeavoured to divest the question at

issue of all that might conceal its bearing and true character. For instance, much has been said as to humus and the part which it plays in agriculture, and it has been my endeavour to bring back the question to its true terms, and to show both by practical facts and scientific arguments that the black matter in farmyard manure is of very secondary importance, and by no means an absolute necessity to agriculture.

To those who advocate high farming by means of farmyard manure I have endeavoured to prove that this system, unless carried on in conjunction with industrial agriculture, which is not often the case, gives neither security nor profit to the grower.

During the last four or five years fresh researches have led me to modify the formulæ of several manures, and to present a general classification of those used at the present time, which sets forth the rules by which we pass from one to another, and also the symbols by which they are expressed and defined.

Notwithstanding all that has been said against experimental fields, it is now clearly proved that their testimony is the only one that can be relied on; the only practical method of fixing with certainty the composition of the soil with respect to the requirements of agriculture. I have therefore dwelt with particular care on the rules that must be followed in interpreting their results, and have shown that, thanks to the ideas they have given us, all the crops on a farm become a source of exact information as to the fertilising agents in which the soil may be deficient.

I then turned my attention to the question of cattle. The subject is an important and complex one, and cannot be approached with too much method and caution. Therefore I first set myself to determine the true place of cattle on a farm, so that I might be able to show with more certainty under what conditions they may become the source of operations capable of yielding a handsome profit. For this purpose I have given a complete and severe analysis of all the results obtained on the Bechelbronn Farm at the time when it was managed by M. Boussingault, carefully separating the three branches of farming crops, cattle and meadow land, in a series of balance-sheets. I have thus been able, by the aid of

reliable figures and positive results, to show what that branch of farming had been in the past when 133*l.* 6*s.* 6*d.* per year had been gained, and what it might become if recourse was had to chemical manures, and if the cattle, instead of receiving insufficient food, were allowed an abundant daily ration, determined according to the rules that physiological science has laid down during the last few years.

It seemed to me advisable also to explain how manufacturing industry might become the handmaid of farming, and how in certain cases it depended on the proper cultivation of the soil. I have already treated this subject in my series of lectures given in 1864, but its importance is so great that I have again alluded to it. The cultivation of beetroot taken as an example has furnished me with the means of giving this portion of my researches a much more practical character than formerly; in one word, this new series of lectures will extend and complete all those which have gone before. We can now tell with certainty to what extent cattle-breeding may be united with ordinary farming, and how it may be made to yield an increased profit, more especially if carried on in conjunction with the cultivation of plants used in manufactures.

This leads me to the consideration of several questions of a new description.

In the course of the last three years I have studied certain branches of industrial chemistry with a view to discover their connection with farming operations. For this purpose I had to consider a large number of interests. These researches were the source of more than one mistake on my part; but I was fully repaid by the fresh information which I gained, and which was hitherto quite unknown to me.

In spite of the efforts, most of them praiseworthy, of large and powerful companies, manufacturing chemistry has not yet succeeded in allying itself with farming in a way that I should like to see. Before this can be accomplished an entirely new order of things must prevail, and I have not the slightest doubt that whenever this shall happen the efforts which I have already made will not be without their value.

But the point upon which I have by preference concentrated all my endeavours for the last three years is the economical and financial part of the agricultural question.

Hitherto agriculture has existed by saving. What is called profit is too often the price of the farmer's own labour and that of his family; but this so-called profit disappears if we assimilate the management of a farm to that of a manufactory, and charge so much for the labour of the chief and of his subordinates in proportion to the amount of capital sunk in the venture.

Let us take Bechelbronn and the Institute of Roville as our examples. Setting aside certain exceptional cases, such as vine-growing, I know but few farming operations which can be carried on at a profit without some manufacture is connected with them, that is to say, if the operations performed are of a purely agricultural nature and nothing is used in the way of manure but that supplied by the farm itself. Of all the attempts which have been made to throw a light on this problem those of Lavoisier are undoubtedly the most important. First of all, it must be remembered that nobody ever fulfilled all the conditions necessary for working out the problem in so high a degree as this great man.

He was more learned than any of his contemporaries, a thorough man of business, with a mind full of the economical and social problems of the day on account of the peculiar nature of his work, and he moreover foresaw the true terms of the great equation which was to solve the agricultural problem.

It was just these very requirements which were wanting in two otherwise most estimable men, who, with less extended views than Lavoisier, entered upon the same path, I mean the late MM. Mathieu de Dombasle and Bella. Read the celebrated paper entitled "Success and Failure in Agricultural Improvements," which was, so to speak, the last will and testament of Mathieu de Dombasle, and which will always remain his highest work. An inexpressible feeling of depression pervades the whole paper. Everything is foreseen, defined and analysed, but with what result? Simply that saving gives the apparent profit. Nothing is to be found of a nature to raise agriculture to the rank of a true industry.

But without quitting the domain of the most moderate practical considerations, I would ask you to tell me, if it were absolutely determined that farming without the help of any

manufacturing adjunct would yield a profit of from 10 to 15 per cent. on the capital sunk at the rate of from 16*l.* to 24*l.* per acre, would this demonstration be a great fact in economic science capable of influencing the public and private welfare of the country to an unlooked-for degree?

Without adding to what I have already said concerning the obstacles thrown by the land laws in the way of the farmer, and our defective laws of inheritance, they nevertheless oppose the establishment of a truly economical system of agriculture. I have endeavoured to find out a way of getting over these obstacles which at first sight seem insurmountable. The obstacle in this case is the law. Not being able to change it, we must rely on the initiative and goodwill of the interested parties, who, by coming to a mutual understanding, may place themselves, so to speak, above the law, and guard their interests by means of properly drawn-up agreements and leases, protecting themselves by means of those generalities which form the backbone of all commercial enterprises, at the same time reserving to themselves that liberty of action without which it is impossible to succeed.

After Article 2102 of the Civil Code we met with the various customary restrictions upon leases which are still in use. First of all leases are granted for too short a period, so much so that the farmer has not sufficient time to recoup himself for the outlay which he has made in improving the property. The prohibition of the sale of straw and fodder, the obligation of following a prescribed order in the rotation of crops, and to have a certain amount of land lying fallow at the expiration of the lease, are only so many restrictive clauses which tie the farmer's hands without any compensation whatever. We can hardly be surprised, therefore, if capitalists look shyly on farming speculations, and that for want of capital the agricultural industry of the country remains in the hands of a class which cannot make any progress in it. So much, however, for a superficial view of the question. Routine, that is to say, rule of thumb, is for the farmer who lacks the necessary capital a guarantee of the small amount of success which he obtains. His life is unceasing work, his method saving all he can in the way of expense, but he risks nothing. In his place you would do the same as he does.

Let us imagine this state of things to be changed. The landlord consents to a lease of thirty years, he executes at his own cost all permanent improvements on the property, such as drainage, roads, farm buildings, etc., and these improvements are made with as little delay as possible and on a combined plan. As for Article 2102, he annuls that by giving the farmer entire liberty to sell his fodder and straw, and even to raise money in advance on his crops. In exchange for this unexampled liberality he requires certain guarantees. In the first place, the farmer must not be a single individual, but with several others must form a joint-stock company, able and willing to provide capital at the rate of 9*l.* or 10*l.* per acre, with a guarantee fund of 3*l.* 4*s.* to 6*l.* 8*s.* per acre. In the second, the landlord must interest himself directly in the speculation, and participate in it by having an *ex-officio* seat at the board of management. As for the acting manager, he must give guarantees of two kinds, personal qualities in the first place, and after these he must show that he has a capital of from 400*l.* to 800*l.*, according to the size of the farm whose management he undertakes, which capital must form part of the common stock during the whole of his management. Beyond this the lease should determine the kind of crops to be grown during the last three years only, the proportion to be observed in the growth of forage, crops to be consumed on the farm, and crops to be sold in the open market. Above all, it should state the quantity and quality of the manure to be brought in from outside; and, finally, in order to facilitate the liquidation of the company's affairs when the lease ends, the standing crops should be valued by a kind of committee of arbitrators, so that the speculation should end at a certain fixed date, and that the interests of every one concerned should be guarded.

With such a lease the tenant need no longer be in dread of the landlord. If the rent is behindhand, it is guaranteed by the company's capital. If the manager acts wrongly, the commercial code will soon set matters right. If he dies, no harm is done, for his affairs are liquidated by his shares being distributed amongst his legal heirs, care being taken that the interests of the company have been duly considered. In this concurrence of interests the landlord has his proper place and

his lawful portion of influence on the board of management, the chairmanship of which might be bestowed on him in the majority of cases.

I know exactly where the great difficulty lies in carrying out such a scheme. It is the choice of the manager, but this you will allow is a delicate matter in all kinds of business. Contrast with a system of farming thus carried out the old method, and you will find great advantages on the side of the new. From the very first the necessary capital for carrying on the operation will have been provided; and the day on which it can be stated with truth that the shareholders are in receipt of 10 or 12 per cent. on their capital, the farm labourer, having within his reach a more profitable method of investing his spare cash than by putting it in the Savings Bank, will take part in the speculation to the success of which he can contribute with his own hand. When we look at the warfare that has been carried on since the beginning of this century between labour and capital, and the attempts which have been made, more especially in England, to put an end to the struggle, and at the excellent results which have been obtained, as is now acknowledged, by allowing coal workers to participate in the profits of the mine, what results may not be expected to accrue from the innovation which I have proposed.

I said a few words just now about the part which ought to be played by the landlord. It seems to me advisable that I should complete my observations on this point. The landlord ought to carry out all those improvements which are calculated to give an increased value to the property. The most important of them are irrigation, drainage, and the construction of buildings; but it must be allowed that all advances for such purposes ought to bear an interest of at least 8 per cent., 5 of which should go to form a sinking fund for the purpose of reconstituting the capital in fifteen years. The capital which the landlord expends being worth 3 per cent. the surplus should be devoted to the above purpose, so that when the capital is once more reconstituted the 3 per cent. contributed by the concern remains his property, and that of his descendants in the form of profit.

In this way the farmer benefits by the rapidity with which

the expended capital is made up, which is another of the good results of the method of farming I have just described.

But you will very possibly ask how it is that I can propose a system of drainage for instance which is to be paid for at the rate of 8 per cent. when the *Crédit Foncier* is content with $6\frac{1}{2}$ per cent.? The answer is very simple. By paying 8 per cent. for fifteen years, the interest taken by the landlord being reduced to 3 per cent., the operation is more advantageous to the farmer than if he paid $6\frac{1}{2}$ per cent. for thirty-one years, with the prospect of having his rent raised at the end of that time when he renewed his lease.

But this is not all. If we fix the amount of capital spent in drainage at, say, 4*l.* per acre at 8 per cent., the amount paid for interest and sinking fund is about 6*s.* 5*d.* per acre. At the rate of $6\frac{1}{2}$ per cent. it would be 5*s.* 2*d.* per acre, a difference of, say, 1*s.* 3*d.* per acre, which is an insignificant difference when we consider that after the fifteenth year the interest paid to the landlord would fall from 6*s.* 5*d.* to 2*s.* 5*d.*, and that the landlord secures the money he has advanced, and will most likely be ready to readvance it for the execution of fresh improvements.

In England there is a clause inserted in the charters of companies which advance money forbidding them to lend money on any agricultural operations which are calculated to yield a profit of less than 10 per cent. on the capital laid out. By means of a rapid sinking fund the operation always shows a profit no matter how small it may be, and is, therefore, equivalent to a safe investment. In my proposal you will find nothing but what daily commercial practice has taught from time immemorial, namely, never to discount the future.

What I have desired to lay before you is the nature of the solutions of the various questions which I am investigating, and if my confidence in this respect required any encouragement in support, I may say with pride that I have found it in the fact that my ideas have been adopted almost before they were made public. Two well-known members of the financial world are engaged at the present time in working a farm of 1,500 acres upon the system which I have already explained. But this innovation is destined to bring

about another of still greater importance, which seems to me to be rendered inevitable by the force of circumstances.

The great evil from which we suffer in France is the excessive subdivision of land; this, it is true, may be diminished by uniting together by means of exchanges a number of very small plots under the direction of a committee of arbitrators, but this proceeding is only a palliative of the evil, and merely an approach towards a more important method of solving the difficulty. Suppose, for instance, that a large estate were to be divided into shares similar to those of a commercial enterprise carried on on joint-stock principles, the shares bringing in, say, from 2 to 3 per cent., and terminable in ninety years. What a strong position would not such an estate occupy if the savings of the country were invested in operations of this nature instead of being devoted to speculating in foreign loans, and if, as I affirm, the agricultural shares bearing a rate of interest of from 10 to 12 per cent. allowed us to mortgage two-thirds of the property at the average rate of 6 per cent.

Under this system France would in less than fifty years be superior to England in her social condition; for property, while still preserving its democratic character, would form the basis of important enterprises spreading over lengthened periods, its creation being protected from the disintegrating action of our law. Inheritance would be by the division of capital instead of by the division of the land. You will see by this rapid sketch that the agricultural question is quite capable of being solved in the way we have been discussing. Let us hope that the rulers of the nation and the owners of the soil, seeing their own interests, will join in this movement. In view of this happy day we may look forward to all those eventualities which our faults and dissensions have bequeathed to our children, with the calm serenity of a nation which, having had great disasters to recover from, nevertheless understands that her soil, combined with a climate like that of France, ought to be her greatest riches.

GEORGES VILLE.

LE GRAND BILBARTEAULT,
23rd January, 1876.

PREFACE

TO

THE FIRST ENGLISH EDITION.

IT is important that both England and France should be alive to the fact that the agricultural crisis from which both countries are now suffering, as well as the more serious troubles which threaten civilised nations, are only the prelude to the economic struggle between the Old World, bound in the trammels of tradition, and the New World, pressing onward free and unrestrained in the path of progress. Guided by a practical spirit, which the Americans appear to possess in an unrivalled degree, they have at their disposal natural resources superior to those of any other country, as well as the advantages assured to them by a constitution which renders the land accessible to all. What the outcome of this struggle will be it is difficult to foresee. We can only define the present state of affairs, and place the results of science at the service of our respective countries.

English economists have taught us that free trade is a certain and unalloyed blessing to the future of nations; that under the stimulus of competition manufacturing operations would everywhere be brought to perfection, that one country would obtain an advantage over another only so far as the products for which its climate, natural richness and native fitness give it a legitimate pre-eminence; and that cheapness of living, or, in other words, the interests of the people, would be the reward of this balance of competition. How little does the experience of to-day confirm these anticipations of future prosperity.

After a civil war almost unparalleled in history, the United States of America found itself suddenly face to face with a

debt whose weight few nations of old Europe could have thrown off. Obligated to provide immediate resources, they could not wait for the theories of classical economists. Without regard to existing opinions as to custom-house duties, they, without hesitation, and contrary to all expectation, levied an almost prohibitory tax on all foreign products. The effect of these measures was immediate. The new taxes enabled America to remain master of the situation and to fulfil her pecuniary engagements. Her manufactures, protected from foreign competition, have sprung up into life and vigour which have placed her at one stroke in the highest rank, as was shown by her display at the last Paris Exhibition. In short, the United States are not only ceasing to be tributary to the Old World, but are becoming its rivals, both in the far East and in our own markets; this is not only the case in manufactures but even in agriculture itself, thus affecting our most important interests. What would be the consequence to France and England if the United States were to offer us permanently their corn and meat at a price lower than that at which we can produce it ourselves? As far as wheat is concerned, there is no doubt that in the United States it can be obtained at about 2s. 6d. or 3s. per bushel. In fact France, in the year 1878, actually received twenty or thirty millions of bushels at this price; and Canada, entering the lists also, is offering meat of prime quality at 2½d. per lb. The whole problem is now reduced to a simple question of freight and carriage.

In the face of such contingencies as these, we cannot allow ourselves to remain indifferent. It is manifest that the struggle in which we are engaged is carried on under conditions the gravity and extent of which will increase rather than lessen in the future. In such a situation our duty is plainly marked out for us. We must first protect ourselves, and then as far as possible regain the market for the goods we formerly exported.

It remains for me to say by what means I conceive this double end may be achieved, so far as agriculture is concerned.

It is an undeniable fact that, except under rare and altogether exceptional circumstances, farming operations carried

on solely with manure produced on the farm itself have for a long time ceased to be remunerative. To obtain certain profit we must have recourse to manufactured manures. In the present work will be found an explanation of this fact, and all the necessary information for preparing the chemical manures best suited to the different crops.

Chemical manures are more used in England than in France; but the French are better acquainted than the English with all that relates to their action, and also to the conditions under which their beneficial effects are most felt, a fact which costs England several millions annually; but if farmers prepare their own chemical manures, they will escape both the adulterations of which they are too often the victims and the high prices which they have to pay. I will quote as one example amongst many a manure very largely used; in 1 cwt. of which there are:—

	Real value.		
	£	s.	d.
Phosphoric acid, soluble in water, 12 per cent. at $2\frac{3}{4}d.$	0	2	9
Phosphoric acid, insoluble, $4\frac{1}{2}$ per cent. at $1\frac{1}{2}d.$	0	0	$7\frac{1}{2}$
Nitrogen in the form of ammoniac sulphate, 3 per cent. at 1s.	0	3	0
	<hr/>		
	0	6	$4\frac{1}{2}$

In all, including the sack, and leaving a margin for minor expenses, the cost will be 7s. 2d. the cwt. Now, this manure is sold at 12s. the cwt. Why do English farmers consent to pay so high a price? Because they pay too much attention to the practical side of the question, and have not applied themselves to the theoretical study of the laws of vegetation.

If, instead of confining myself to this example, I were to analyse in the same way the manures from the best English manufactories, I should be led to the same conclusion. They are all burdened by high profits, paid by the too credulous and, in many cases, too confident practical agriculturist. English farmers possess an infallible means of becoming enlightened in this respect. Let them consent, if only once, and by way of experiment, to compound for themselves the artificial manures they require, according to the formulæ I have laid down, and then try them side by side with those they have been in the habit of buying. I know beforehand

what the verdict will be. If the agriculturist of the present day wishes to resist successfully the danger which threatens him, he must manure his land plentifully, whether he is cultivating grain, root or fodder crops, and he must procure manure whose composition may be relied upon. With this object there should be formed in every county one of those co-operative societies, now becoming so common in England, to the success of which there are few obstacles. The difficulty of manufacture may be suggested. But it is only a question of making simple mixtures of the different salts, for which there are machines equal to every requirement. Calcic superphosphate is rather more difficult to manufacture, on account of the necessity of procuring the sulphuric acid. But when a co-operative association has secured the services of a practical chemist, this difficulty vanishes. The result is well worth the trouble. The farmer will for $2\frac{3}{4}d.$ per lb. obtain a soluble phosphoric acid, for which manufacturers have been charging him about $6d.$

The more I reflect on the condition of agriculture in France as well as in England, the more fully convinced I am that these co-operative societies for the manufacture of chemical manures would be of the greatest benefit to both countries, especially if they were under the management of a small select committee, chosen from those scientific chemists who are the greatest authorities on the subject, and who would act as the disinterested advisers of the manufacturer. The establishment of such associations would result in the annual saving of millions of pounds; and through that economy and the general use of chemical manures of superior quality, the increase in production would amount to from forty to eighty millions sterling.

If any doubt exists as to the correctness of this calculation, we have only to reckon what a saving of 20 per cent. in the cost of manure, and an increase of 10 per cent. on the production of crops, will represent annually.

Amongst the substances which influence plant life, ammoniac sulphate is one of the most important; and, unfortunately, the sources from which we obtain our supplies are at present limited and inadequate. Now there exist within our reach inexhaustible quantities of nitrogen for producing

ammonic sulphate, *viz.*, the nitrogen of the atmosphere. Many experiments have been made with the view of utilising this nitrogen; but, unfortunately, the results hitherto obtained have only been of theoretical interest. And yet no discovery would be more useful or important. Ammonic sulphate at 1*l.* per lb. means cheap bread and cheap meat. What is to be done to hasten forward this state of things? The best way seems to me to be to offer a prize of 100,000*l.*, collected by international subscription, for the discovery; and if the English farmers regard this proposition with favour, I beg to have the honour of placing my name at the head of the first list for 40*l.*

With large quantities of chemical manure at a reduced price, agriculture both in France and England will be able to hold its own against the competition of the United States. But in order to make the best of this advice we must take another step in advance, and break through the worn-out tradition which mistook the true function of water in irrigation. If in the future we recognise that the universal practice of irrigation is only a supplement to the beneficent action of rain, by maintaining the earth in a constant state of moisture equal to that of the most fruitful years, agriculture will be second to no other branch of industry in the large profits which it yields.

With respect to manures and the questions connected with them, the United States have not remained behindhand. The book which I now offer to the English public has been translated more than once in America, and I now quote the terms in which the Georgian Society of Agriculture has been good enough to express its appreciation of the character and utility of my work:—

“Mr. Barnett, of Wilkes, offered the following preamble and resolution:—

“‘*Whereas*, the exceedingly interesting work of Georges Ville has done so much to advance the science of agriculture among mankind, and to promote it almost to the rank of an exact science by its author’s wonderful combination of skill, knowledge and common sense . . . this society earnestly recommends its circulation, as furnishing the means of enlightenment to the most advanced farmers, both in the

knowledge of facts and of the principles of investigation and experiment, leading to the further increase of knowledge.'

"The resolution was adopted by a unanimous vote of the Convention.

"Mr. Fannin, of Troup, offered the following resolution, which was adopted:—

"*Resolved*, that we, as representatives of the County Agricultural Society, will endeavour to promote the circulation of the work of the distinguished agricultural writer, Georges Ville, and will recommend to the societies to subscribe liberally, and to take not less than six copies each; that, in addition to this, the County Societies, instead of offering cups for premiums, will offer a copy of this work.'"

I hope that the reception of this book in England will not be less favourable than in America, for it has the good fortune to have for its translator a scientific man, who at this time has become conspicuous by his brilliant discoveries and profound researches—Mr. William Crookes, a Fellow of the Royal Society, whose friendship I am proud to possess, and to whom I take this opportunity of rendering my most sincere thanks.

GEORGES VILLE.

22nd February, 1879.

NOTE BY THE TRANSLATOR.

To prevent unnecessary fractions, the English ton has been taken in large quantities as equivalent to 1,000 kilos, but the lb. in smaller quantities has been reckoned at 4545 kilos, and the £ sterling at 25 francs. The hectare has been considered equal to $2\frac{1}{2}$ acres, and the hectolitre to $2\frac{3}{4}$ bushels.

PREFACE

TO

THE SECOND ENGLISH EDITION.

THE doctrines advocated in this book, which at the time of its publication were quite new, and appeared to some extent revolutionary, have been vindicated by the experience of agriculturists both in England and France, and for many reasons the issue of a new edition of the work appears desirable. It is only just that its claims to be regarded as a classic and its author's right to the title of pioneer should not be forgotten, when many of Professor Ville's views are so generally adopted that his prescience and acumen are likely to be underrated and his priority unrecognised. Again, in a new edition some alterations could very well be made which would render the book more useful to the English agriculturist, who is confronted with very different conditions as regards soil and climate from those which surround his colleague in France. Moreover, agricultural science has made remarkable progress in the last thirty years, and the altered practice calls for some changes in the text, while the farmer has now a far greater choice of artificial fertilisers than was procurable at the time when the book was written. In passing, attention may be called to the complete fulfilment of the author's prophecies as to the growth of the manufacturing industry of artificial manures.

The changes which have been found necessary in the third edition include the adaptation of the formulæ given in the original to practicable prescriptions. Potassium nitrate as an ingredient has been eliminated, since its price prohibits its use on a large scale ; moreover, the doses of manures, which were in many cases too large, have frequently been cut down

to more suitable dimensions. Advances which have been made on the purely scientific side are noted ; for instance, the chemical analysis of the soil which the author regarded as useless has now been modified in such a way as to yield distinctly valuable and directly comparable results. Finally, some pages of new matter have been added. The fertilisers such as basic slag and kainit, which have come into use recently, are now included in the Appendix on the Ingredients which enter into the Composition of Chemical Manures, and a new chapter has been added on the utilisation of the nitrogen of the air for purposes of plant feeding. Such methods as have been found practicable are described, and where a new fertilising agent is the product of the process, as in the case of calcium cyanamide, the results of trials of its usefulness and applicability are given as far as possible up to the date of publication.

Every endeavour has, however, been made to preserve the spirit of the original, which, as an exposition of the principles underlying the use of artificial fertilisers, is unrivalled ; the great bulk of the text is still a literal translation of the author's words. It is hoped that the appearance of the new edition will be regarded as opportune, coming as it does at a moment when a revival of interest in agriculture is a clearly discernible sign of the times.

The Editor wishes to express his indebtedness to Professor Percival, Director of the Agricultural Department of University College, Reading, for his careful revision of the original instructions for compounding the different classes of chemical manures, and for replacing many of the formulæ given by Mr. Georges Ville in the French edition by corresponding formulæ more suited to English climate, soils and modes of agriculture. Professor Percival also has rendered valuable assistance in revising, and in many cases rewriting, new matter descriptive of the uses of basic slag, kainit and other chemical manures which have come into use since Georges Ville's time.

WILLIAM CROOKES.

May, 1909.

ON CHEMICAL MANURES.

PART I.

THEORY AND PRACTICE.

LECTURE I.

PLANTS—THEIR COMPOSITION, GROWTH, NUTRITION, AND CULTIVATION—CHOICE OF MANURE.

It has been my annual custom since the year 1861 to give a course of public lectures on the results of my researches into the newest and best methods of maintaining and increasing the fertility of the soil. The information thus gained is essentially scientific both in its character and origin, but I have endeavoured to render it as clear and practical as possible by omitting theoretical formulæ, except in those cases in which it is absolutely necessary for the perfect comprehension of the subject.

The importance of agricultural questions is every day more keenly felt. For a country can only obtain lasting prosperity by excelling all other countries to which its commerce is open. It must of necessity produce more, and that, too, with greater economy.

The object of the present course of lectures is to consider the means by which this end can be attained.

In approaching the subject my thoughts revert, not without emotion, to the time when an august personage deemed my first labours worthy of encouragement. Many then doubted these results, because they were founded only on laboratory experiments, and they could not be convinced that it was possible, as I had stated, to regulate the effects of vegetation by means of the elements which chemistry discovers in plants, and to found on their use a new system of agriculture.

The late Emperor Napoleon III., however, judged otherwise, and the fact of a field at Vincennes being set apart for experiments, was yet another proof of the enlightened solicitude of that sovereign for our agricultural interests.

To attain the end I have in view, I must first explain the actual elements of which plants are composed, since it is to these elements that agriculture will in future have to resort in order to increase its returns. I must, as it were, decompose the actual substance of the plant, and demonstrate that it is

possible to analyse it with perfect precision and exactness, and this in spite of the varied forms it affects, more than 200,000 different plants being known to exist.

This leads to the mention of facts of a different order, one of which is that, in plants, nothing is stable or constant, their elements are subject to certain transpositions in the heart of the various organs, and these displacements follow a permanent law of order of succession.

We must, however, go still further: the vegetable kingdom is dependent for its growth on certain imponderable agents, light, heat, and chemical affinity, and it is absolutely necessary to possess a knowledge of the nature of their effects if we wish to avail ourselves of their aid.

Useful results and advantageous applications must be the chief end we have in view, and this will be attained with greater certainty if our deductions and precepts, exempt from all empiricism, are borne out by the theoretical data which have preceded them.

Chemical analysis shows that about fourteen elements enter into the composition of all kinds of plants: they are divided into organic and inorganic elements, the former being carbon, hydrogen, oxygen, nitrogen, and the latter, phosphorus, sulphur, chlorine, silicon, iron, manganese(?), calcium, magnesium, sodium, and potassium.¹ This limited number of elements possesses such an infinite power of combination, that they are capable of forming the enormous variety of plants to which I have already alluded. They resemble, in fact, the letters of an alphabet—few in number but sufficient to form all the words of a language.

It must not, however, be thought that the composition of plants is the same throughout the various organs, differing only in form; that the stem, the bark, the leaves, and the fruit are only different phases or developments of one and the same substance, which can at all times be identified. Each organ has to a certain extent a composition peculiar to itself, but, as will presently be seen, these dissimilarities are a consequence of the conditions needed for the reproduction of the species, and may be reduced to very simple proportions.

It may be laid down as a general rule that the foliaceous or fleshy parts of plants contain more mineral or inorganic matters than the woody and fibrous portions. These variations are caused by the aqueous portion of the sap evaporating more quickly in the former than in the latter parts. In fact, the less compact the tissues are, and the more direct their communication with the atmosphere, the more rapidly does

¹ Traces of copper and fluorine are also present.

this evaporation proceed. Further, more mineral matter is found in herbaceous plants than in trees, more in the leaves than in the bark of a tree, and more again in the bark than in the sap wood and heart wood.

In leguminous plants there are two distinct parts, the pod and the seed. The pod, which is in immediate contact with the atmosphere, lends itself more readily to the evaporation of the sap: consequently it contains more mineral matter. In the same way I may mention that the leaves of evergreens, which are renewed in the winter—a season less favourable to evaporation than the hot summer—contain on this account less mineral matter than those of other trees.

The following table exhibits in a more exact form proof of what I have stated:—

Mineral matter in 100 parts of vegetable substance in dry state			
Herbaceous plants	.	.	7·84
Trees	.	.	0·99
Wood	.	.	0·55
Sap wood	.	.	2·65
Bark	.	.	7·47
Leaves	.	.	14·20
Fallen leaves	.	.	6·60
Persistent leaves	.	.	2·00
Pea shells	.	.	5·50
Peas	.	.	3·10

If to each inorganic element in particular we apply the researches we have just made on the whole, we shall arrive at an analogous conclusion, and shall find that by a sort of election each of these elements is concentrated by preference in certain parts of the plants; thus more silica, lime, ferric oxide, sulphates and chlorides, are found in the stalks and leaves than in the fruit and seeds, in which phosphoric acid, potash and magnesia become on the contrary the predominant elements.

We will take wheat for example:—in the ash of the grain there is 46 per cent. of phosphoric acid; in that of the husk 2·54, in that of the straw, 2·26, and only 1·70 in that of the root.

What I have said of phosphoric acid applies equally to magnesia and potash, the proportions of which vary in the different parts of the plants in which these salts are found, as will be seen by the following table:—

	In 100 parts of ash of		
	Roots	Straw	Grain
Phosphoric acid	1·70	2·20	46·00
Magnesia	1·97	3·92	13·77
Potash	2·87	15·18	32·59
Lime	0·88	3·00	1·19

Similar differences to those found in wheat also occur, without exception, in all plants.

The distribution of mineral matter is not, therefore, left to chance, but is on the contrary subject to a fixed law. Many kinds of mineral matter participate jointly in the formation of plants, but each is concentrated by preference in an organ, or in a determined system of organs. It remains for us to find the reason for this unequal distribution.

In the economy of nature all the functions of living beings, however varied they may be, tend towards the same end, viz., to assure the reproduction of the species, that is to say, to ensure its permanence for all time. They are regulated with a view to this important result, but that this condition may be fulfilled the embryo contained in the seed must find within reach of its vital power those elements which are indispensable to the first acts of plant life. This is why the seed is so abundantly provided with phosphoric acid, potash, and magnesia. It is a sort of reserved force provided for the first evolution of the embryo. An examination of the preceding table shows the difference between potash and phosphoric acid. Phosphoric acid is in almost uniform proportion in all the organs except the seed: it is not so with potash; the concentration of the phosphoric acid in the seed takes place suddenly; the proportion of potash, on the contrary, increases by degrees, and the closer the parts approach to the seed the more considerable this proportion becomes.

A very old observation of Theodore de Saussure will explain this sudden passage on the one hand and the gradual progression on the other. The reason is that the calcic and magnesian phosphates are insoluble in water, but a double phosphate of potash and lime, and a double phosphate of potash and magnesia, exist, which are both soluble.

Alkaline phosphates favour, if they do not determine, the transport of earthy phosphates to the heart of the tissues. Now as at the time that the seed is formed, vegetation slackens and the organs begin to dry up, it is manifest that the superabundance of alkaline salts must assist in the conveyance of earthy phosphates. It follows that the nearer we get to the seed, the greater the proportion of salts of potash required to set free the last portion of earthy phosphates.

In speaking of the distribution of the organic elements we are struck with the fact that, although only four in number, they represent at least 95 out of 100 parts of the substance of plants. It must not, however, be imagined, that because the inorganic elements figure less largely than the organic, that therefore their function is a less important one. In their

absence vegetation is impossible, and as soon even as the soil is insufficiently provided with any of them it becomes languid and puny.

In their distribution in the economy of plants, the organic elements present yet another contrast to the inorganic elements. Three of them, carbon, hydrogen, and oxygen, are present in almost invariable proportions. All plants and all the various organs, without distinction, contain them in similar quantities. Trees, bushes, simple plants, roots, stems, barks, branches, leaves, fruits, and seeds, show an almost invariable proportion of carbon, hydrogen, and oxygen.

This is not the case with nitrogen: it varies in a similar way to the phosphoric acid and potash. Fruit and seeds contain more than other organs, because during the whole process of germination the embryo lives at the expense of the seed, and therefore requires to find in the circumscribed limit of its activity not only mineral matter, but also nitrogen.

We have seen then that the substance of plants contains carbon and oxygen in the proportion of from 40 to 45 per cent., hydrogen from 5 to 6 per cent., and nitrogen from 1 to 2 per cent.

In looking further into this subject, I would point out that it is not enough to be able to tell of what plants are composed; we must also discover how they are formed, and in what manner their elements combine in the interior of the organs, whose evolution and growth they determine. Here the method differs entirely from that suited for mineral matter. When a solution of sea-salt is exposed to the heat of the sun, crystals are deposited as the liquid is evaporated, which at first are so minute that they can be distinguished only with a magnifying glass; soon, however, their isolated forms become visible to the naked eye, and we can watch their growth from day to day, and note that this development takes place with a geometrical regularity that reveals the existence of a primordial law which governs them, and from which they cannot deviate.

In this case the increase takes place by the successive and continuous deposit of new layers of salt; the layers being added to all the surfaces of the first crystal, which constitutes a sort of attractive centre for the molecules of salt diffused in the liquid.

The process of vegetation is not equally simple: the phases through which a plant passes before attaining its full development are nevertheless of so fixed and permanent a character, that it is evident that a plan exists, the economy and constancy of which exclude all ideas of chance; a plan which, though very different from that governing the formation of

minerals, depends upon no less inflexible laws, which are equally well known to us, both in principle and in detail. I have said that plants owe their formation to some fourteen different elements: I may now add that some of these elements originally existed in the air in the gaseous state, whilst the others, whether liquid or solid, emanated from the soil.

The former are absorbed by leaves, the latter by roots: hence plants are formed and developed by means of many and diverse substances derived from various sources, but these substances do not all at once assume the form of tissues and organs: they first pass through the more simple or preparatory stages, in which, although they have not completely assumed the peculiar characteristics of organised bodies, they can no longer be regarded as belonging to inorganic nature.

The growth of a plant is then in reality an operation consisting of two distinct stages. The unstable compounds by the formation of which plant growth begins may be divided into two groups—one including those compounds composed entirely of carbon, oxygen, and hydrogen, and the other those in which we find, in addition, nitrogen, sulphur, and phosphorus. Below is a list of these products, to which I have given the name of *transition products* of vegetable life, as this title denotes at the same time their origin, their principal characters, and their chief uses:

Transition Products		
	Carbo-hydrates	Nitrogenised
Insoluble in water . . .	{ Cellulose Starch	Fibrin
Partly soluble in water . .	{ Gum Tragacanth Pectin	Casein
Soluble in water . . .	{ Arabin Mucilage Grape sugar Cane sugar	Albumen

All these products of the first group, to which we shall give the generic name of *carbo-hydrates*, have a common character: their composition is the same, or if not actually identical, is near enough for us to express it generally by the symbolic formula, $C_6(H_2O)_n$.

In all these compounds there are always six combining proportions¹ of carbon in combination with hydrogen and

¹ In chemistry a combining proportion is the proportion expressing the weight, or quantity by weight, of any substance which combines with another substance to form a definite compound.

The combining proportion of hydrogen is		1
“	“	oxygen “ 16
“	“	carbon “ 12
“	“	nitrogen “ 14

oxygen in the proportion required to form water. Although dissimilar in appearance, all these bodies are in reality only a reproduction of the same type; this is proved by the impossibility of establishing a precise line of demarcation between them. A closer study of these remarkable products will plainly show the point beyond which all precise and absolute distinction is impossible.

I have placed at the head of the first group cellulose, which forms the structural tissue of plants; immediately after which comes starch, then the gums, and lastly sugar. The differences between cellulose and sugar are so numerous and important, that unless we were acquainted with the other terms of the series—pectin, inulin, gums, &c.—we should never dream of any similarity of composition existing between two bodies apparently so unlike. Cellulose, for instance, is insoluble, while sugar is soluble in water. Cellulose is neither affected by cold dilute acid nor by slightly dilute alkaline solutions, while sugar is acted upon by both. Sugar has a sweet taste—cellulose is tasteless.

The identity between these two bodies, however, becomes manifest, and in a measure forces itself upon us, when, instead of limiting the comparison to cellulose, we consider the properties of the other terms of the series, and the gradations of which cellulose is itself susceptible. Cellulose in the state of ligneous tissue is insoluble in cold, and even in boiling water; but in Iceland moss—a variety of lichen peculiar to regions of the north—the cellulose is much less compact, and when boiled is converted into jelly. It is as hard as ivory in the stones of certain fruits, but is so soft as to become edible in the mushroom. There is no more difference between the sugar and the cellulose of lichens than there is between the fleshy part of a mushroom and a piece of oak.

Between starch and cellulose there would seem to be little analogy, for starch in the potato exists in the state of isolated granules, each granule being formed of concentric layers fitting one over the other like the layers of an onion; yet starch swells in boiling water; its granules lose their structure and form like Iceland moss a true jelly, so that an incontestable analogy does exist between these two products.

Inulin, which is found in the Jerusalem artichoke, and which is a starch-like compound, is dissolved in boiling water, from which it is separated as the water cools in the form of distinct granules, while, as we have seen, starch swells in boiling water, but does not dissolve.

Gum tragacanth (Bassorin), too, forms a jelly in cold water without dissolving, while arabin swells and dissolves, and has moreover a sweetish taste. Thus the passage from gum to sugar becomes manifest, and the analogies which connect sugar with cellulose are, I hope, more apparent. I may, however, add that cellulose, even when it is in its most compact state, can be converted into gum and into sugar by treating it with sulphuric acid. This may also be done with all the other terms of the series. Such transformations are incessant in plants: indeed, the economy of plant nutrition depends upon them.

The second group of transition products are the albuminoid bodies, which are three in number: they are distinguished from the carbo-hydrates by containing nitrogen, sulphur, and phosphorus, which are lacking in the first group.

Their composition, then, shows them to be a degree higher and more complicated. What we have said of the carbo-hydrates, however, holds good for the albuminoids, notwithstanding their dissimilarity; they are in reality the same bodies in three different states. Their empirical formulæ are expressed in a very complicated manner, no two authorities agreeing.

It may be objected that fibrin is insoluble, while casein and albumen are soluble in water. I have, however, already remarked that it is only necessary to raise the water to boiling point to render these two last bodies also insoluble. The question may also arise: how is it that heat does not act on solutions of albumen as it does on solutions of casein, and further, that while albumen coagulates in a mass, casein only partly coagulates by forming pellicles on the surface of the liquid? To answer this we need only say that it only remains for us to communicate to either of these three bodies the properties of the two others.

Fibrin is insoluble. To render it soluble it must be beaten in a mortar with potassic nitrate, adding to it a fiftieth part of its weight of caustic soda. The solution thus produced possesses all the properties of albumen, including its most distinguishing characteristic, viz., that of coagulating in a mass by the action of heat. If a few drops of caustic soda be poured into a solution of albumen, it immediately acquires the property of coagulating like casein in the form of pellicles. Like the carbo-hydrates, these bodies are incessantly being transformed into each other at every period of plant life, thus showing that they are only variable forms of the same type. A little consideration will show that these transformations form the very essence of plant life.

Wheat, before it germinates, contains from ten to fifteen per cent. of fibrin, and at most, only one or two per cent. of albumen. As soon as germination begins, the proportion of fibrin diminishes, and that of albumen increases. Beans and lentils contain casein, but no fibrin, and very little albumen, but during germination the casein disappears and albumen takes its place. The same thing occurs with starch, which seeds contain in abundance; it is changed into gum and sugar, which, in their turn, undergo a fresh transformation, passing into cellulose in the leaves, stems, and roots.

A plant in its earliest stage is nothing more than a seed transformed. After germination, when vegetation properly speaking begins, more albumen is formed continually, until the plant blossoms, when the albumen is changed to fibrin in wheat, and to casein in beans and lentils.

Returning to the carbo-hydrates, I may quote the example of beetroot, which contains from eight to ten per cent. of sugar before blossoming, but none when the seed is formed, the sugar having again taken the form of starch.

I repeat then that plant nutrition is a phenomenon consisting of two stages, the first being the formation of transition products, the second the transformation of these products into the tissues and organs of plants.

We have now considered both the composition of plants and their mode of growth. To complete the general sketch it remains for me to refer to the conditions which regulate plant life, which in the practical order of things renders the culture of the soil prosperous or precarious, expensive or remunerative. These conditions are three in number:—

1. The climate.
2. The nature of the soil, under which head we may also consider the choice and quantity of manures.
3. The choice of seed.

The influence of climate is incontestable. Who has not noticed the difference in the growth of vegetation at the foot and at the summit of a mountain? Upon the slopes of the Alps, for instance, stretches of verdure may be observed at only one or two thousand yards' distance from each other, but differing, not only in luxuriance and colour, but also in the nature of their flora.

The same fact is reproduced upon a larger scale from the Equator to the Poles. You know that at the Equator vegetation is marked by a vigour and grandeur which calls forth the admiration of the European traveller. The number of trees as compared with herbaceous plants is more considerable than in Europe; they are remarkable also for their greater elevation

and the size of their trunks, as well as for the richness and variety of their foliage.

Beyond 70° of latitude trees, shrubs and herbaceous plants are, on the contrary, very small, and in the neighbourhood of the Poles vegetation is represented solely by a few powder-like cryptogams and crust-like lichens, which creep over the surface of the soil.

Climate, then, exercises a wonderful influence on plant production, and we should indeed be unwise if we failed to take this into account. Would it not, for instance, be foolish to try to cultivate the vine at Dunkirk, maize at Valenciennes, or olives in the plains of La Beauce? No one would of course attempt this; but the agriculturist of our day ought to try more and more to specialise and to turn to account the favourable chances of climate. With free trade and facility of exchange every country and province ought to create for itself the monopoly of products in which it can defy competition. Why should the South try to grow corn when it can be obtained more cheaply from the North in exchange for wine and olive-oil? The English, who are a prudent and thrifty people, have, for a long time, understood this, and wherever the climate is too damp for corn to be grown with profit, they substitute meadow land for arable, and devote their energies to cattle-grazing.

Amongst the conditions that influence vegetation we have placed in the second rank the composition of the soil and the choice of manures. Now two contiguous portions of land frequently differ greatly in fertility. Such differences may be accounted for by the presence or absence of certain agents which abound in the one place and are lacking in the other. By adding to the less favoured soil the elements in which it is deficient it immediately becomes fertile: therefore, by means of proper manures, we acquire in a case of this kind an almost limitless power; man in fact commands Nature. It is to the study of the second condition, the choice and use of manures, that the course of instruction at Vincennes is specially devoted.

The third condition regulating plant production, viz., the choice of seeds, differs from the two preceding ones, which belong to the exterior world, in that it has its origin in the plant itself.

All the different species are susceptible of certain changes which are capable of becoming hereditary. Races and varieties have no other origin. Unimportant in a botanical point of view, these deviations often become of great importance in agriculture, because under the same conditions of soil and manure one variety often produces twice as much as another.

For three years I grew two parallel patches of wheat, one being English red wheat, the soil and the manure were the same in both cases. The English wheat thrived wonderfully, whilst the other, notwithstanding the great care taken with it, turned out badly. During the autumn it always showed a marked advantage over the English sort; but in the spring, although some late frosts occurred, it was attacked by a red rust, whilst the English corn being less advanced took no harm whatever.

There is then a course of action open to us which depends mainly upon ourselves, and which has not hitherto received all the attention it deserves. I firmly believe our vegetable species to be susceptible of as great improvements as have been effected in the different breeds of domestic animals.

It is to the second of the three conditions which regulate the growth and products of vegetation—that which governs the choice and quantity of manure—that our attention will now be specially directed. I have only mentioned the other two, for the thorough definition and comprehension of our subject in all its aspects. It is possible that I may be reproached with the too scientific character of these researches, but it must be remembered that if practical results are to be our aim, science must be our guide and its principles the fundamental basis of our deductions.

Till within the last twenty years it was thought that farmyard manure was the only fertilising agent. We maintain that this is wrong, and that it is possible to compose artificial manures superior to and at the same time cheaper than farmyard manure.

It has been said again and again that pasture land is necessarily the starting-point of all good farming, on account of the cattle raised and the manure produced, but in our day farmyard manure has irretrievably lost the character of being absolutely necessary to agriculture as artificial manures have been proved to be unquestionably more remunerative.

In attempting to prove the truth of the above statement, we must first define the degrees of utility of the various elements of which plants are composed, search out the forms under which their assimilation is most easy and their useful effect the most certain, and, finally, we must lay down the rules according to which they must be combined, in order to form powerful and efficacious manures.

LECTURE II.

ASSIMILATION OF CARBON, OXYGEN, HYDROGEN AND NITROGEN —NITROGENOUS MANURES.

IN my first lecture I stated that the elements are very unequally distributed in the various parts of plants, in which many of them form temporary combinations before becoming converted into tissues and organs. It is necessary, in order to complete this preliminary inquiry, to consider in what state the elements are found in Nature, under what form the plants absorb them, and in what measure it is possible by their aid to act on the products of vegetation.

I will begin with carbon. The quantity of carbon that enters into the composition of plants is, in round numbers, from 40 to 45 per cent.: it therefore plays an important part in vegetation. When I state, however, that to the agriculturist it is absolutely unimportant, and may be excluded from manures without the fertility of the soil being affected, I shall appear to be contradicting myself. To prove, however, that the contradiction is only apparent, I need only remark that the carbon of plants has its origin in the carbonic dioxide of the air, and that the atmosphere furnishes an inexhaustible supply.

I might, then, abstain from speaking of the assimilation of carbon, and in many respects the omission would cause no inconvenience. I have, however, resolved to go rather deeply into the subject, and this for two reasons:—First, because the explanation of this phenomenon marks an epoch in the history of science; and, secondly, because its study will help us in bringing to light that which forms essentially the distinctive character of plant production.

The assimilation of carbon is effected by a very simple process. Carbonic dioxide, formed by the union of carbon and oxygen, is absorbed by the leaves in the substance of which it is decomposed, the carbon being retained by the plant whilst the oxygen is set free. This simple but wonderful phenomenon is one which can only be produced in the chemist's laboratory by the aid of the most complicated

methods of analysis; yet it is effected by the delicate tissue of a leaf without its fragile organisation being in any way impaired.

It will be observed that this process is the reverse of that of animal respiration. Green plants under the action of light absorb carbonic dioxide and give back oxygen, whilst animals, on the contrary, inhale oxygen and return carbonic dioxide. This explains why the composition of the atmosphere does not change notwithstanding the incessant supplies drawn from it by both animals and plants.¹

But there is a deeper and perhaps a still more mysterious order of phenomena, the study of which tends to reveal the true character of agricultural production. As a general rule, all labour, to be productive, presupposes two things, both alike indispensable, viz., a raw material and a source of power, and notwithstanding all our efforts the raw material is subject to waste which we can endeavour to lessen, but which cannot be entirely prevented. This observation applies also to the power expended which is only partially utilised. Take, for example, such industrial arts as metallurgy, weaving, &c. The labour is always accompanied with a double loss of raw material and of power. This loss is caused by the friction of the machinery used as well as by its imperfection.

In agriculture, however, the character of the production is quite different. The earth yields a harvest ten times greater than the fertilising agents employed, and each harvest involves an expenditure of power at least five hundred times greater than is actually exerted. The principles on which the assimilation of carbon depends will show how these two apparently irreconcilable facts can be explained.

It has already been stated that all plants contain from 40 to 45 per cent. of their weight of carbon. Now, if carbon is absorbed from the air and forms part of the fertilising agents used in agriculture as well, it is at once evident why it is that the soil yields more than it has received. The same remark applies to oxygen and hydrogen, which represent more than 50 per cent. of the weight of plants, and which both have their origin in water. It follows from this that 95 per cent. of the substance of plants is derived from sources foreign to the soil, and that the portion which human industry has to furnish to the earth is only a fraction of that which is yielded

¹ Plants have a true respiration identical with that of animals, but the amount of carbonic dioxide which they exhale is trifling in comparison with the quantity of pure oxygen which they give out. Whether the composition of the atmosphere remains permanent or is changing is not yet known.

by the crops. This fraction is, however, indispensable, for without it the carbon of the atmosphere, and the oxygen and hydrogen of water, would not have been able to enter into plant life.

The excess in the earth's produce is therefore due to the air and rain.

The following table, which applies to other plants as well as to wheat, is a conclusive proof of this fact:—

Composition of Wheat (Straw and Grain).

In 100 parts.			
Carbon . . .	47·69	}	These 93·55 parts are derived from the air and rain.
Hydrogen . . .	5·54		
Oxygen . . .	40·32		
Soda . . .	0·09	}	Total, 3·386. The soil is superabundantly provided with these constituents, which it is quite unnecessary to add to it.
Magnesia . . .	0·20		
Sulphuric acid . . .	0·31		
Chlorine . . .	0·03		
Ferric oxide . . .	0·006		
Silica . . .	2·75	}	Total, 3·00. These the soil possesses only to a limited extent, and the deficiency is supplied by artificial manure.
Manganese . . .	(?)		
Nitrogen . . .	1·60		
Phosphoric acid . . .	0·45		
Potash . . .	0·66		
Lime . . .	0·29		
<hr/>			
99·936			

The second characteristic of agricultural products, although of the same order as the preceding, is more difficult to understand.

Till within the last twenty years it was held that natural phenomena were due to different causes because they affected different organs.

A more correct method of observation has, however, taught us that this multiplicity of causes was only apparent, and that in reality all physical phenomena are only the manifestations of a single cause, viz., motion. The combustion of a body is followed by an increase of temperature. The combustion of 1 lb. of carbon produces a degree of heat sufficient to raise 14,400 lbs. of water 1° F. The quantity of heat necessary to raise 1 lb. of water 1° F. is termed a *heat-unit*, so it may be said that 1 lb. of carbon produces 14,400 heat-units. By heat, mechanical power is engendered, and between the body burnt, the temperature produced, and the power derived therefrom, there is an invariable relation.

It is known with certainty that a heat-unit is equivalent to an effort necessary to raise 1 lb. to a height of 772 feet, and the effort necessary to raise 1 lb. 1 foot is called a foot-

pound or dynamic unit. Hence one heat-unit, or the quantity of heat which causes 1 lb. of water to rise 1° F., is sufficient to elevate that same pound to a height of 772 feet, or, in other words, one heat-unit is equivalent to 772 foot-pounds.

The work of a horse is estimated at 1,980,000 foot-pounds per hour, that is to say, the strength he exerts is sufficient to raise 1,980,000 lbs. 1 foot high. Estimating the day's work at 8 hours, he will therefore have raised 15,840,000 lbs. to the height of 1 foot in that time.

But if a heat-unit is equivalent to 772 foot-pounds or dynamic units, and if the combustion of 1 lb. of carbon produces 14,400 heat-units, it follows that the combustion of 1 lb. of carbon corresponds to 11,116,800 foot-pounds, or, in round numbers, to $\frac{3}{4}$ day's work for a horse, the day being reckoned, as I have already said, at 8 hours.

Now it is clear that the combustion of carbon generates carbonic acid, and produces heat, which may be expressed in dynamic units. If it were required to undo the work of combustion, viz., to separate the carbon from the oxygen in the carbonic dioxide, it would be necessary to restore to these elements a quantity of heat equal to that resulting from their combination.

These calculations show that, as the yield of 1 acre may be fixed at 8,800 lbs. of vegetable matter, containing on an average in round numbers 4,400 lbs. of carbon, the fixation of which required over 63,000,000 heat-units, that quantity of heat corresponds to nearly 49,000 millions of foot-pounds, that is to say, to the work done by a horse in 3,088 days: therefore the harvest of 1 acre is obtainable at this cost.

If, then, the preparation of 1 acre by ploughing, harrowing, &c., requires from man and beast only the amount of labour equal to that of a horse for six days, it follows that where man expends four-tenths in mechanical efforts, nature adds to it 205 by the imperceptible action of heat and light. The source of this enormous consumption of active and inexhaustible power is to be found in the rays of the sun, in the absence of which plants do not assimilate carbon. The heat given out by wood and other vegetable products, when they are burnt, is nothing more than the heat which they themselves have drawn from the sun during their formation, and which passes, by combustion, from the latent to the free state. It is then in reality only an act of restitution.

This explanation will, I think, show clearly what are the characteristics of plant production. Nature alone possesses the privilege of adding to the raw material, which in other cases suffers a loss; and of yielding a relatively enormous

product, the formation of which shows that an invisible force has been at work, and one which is quite independent of our efforts.

It is in this that we discover the marvellous instinct of those nations who, anticipating the discoveries of science, have believed that the prosperity of a state cannot be lasting except its agriculture is in a flourishing condition.

I have entered fully into this matter, because I am convinced that in order to thoroughly comprehend the best agricultural methods, it is first necessary to have a clear idea of the principles upon which they are based.

Now the assimilation of carbon resolves itself, as we have said, into two facts. Plants absorb carbonic dioxide from the air and decompose it.

To show that leaves absorb carbonic acid, it is only necessary to put a branch of vine-leaves into a glass receiver, and to pass into it a current of air. Before entering the receiver the air contained from three- to four-thousandths of its volume of carbonic dioxide, but when expelled it contains only two-thousandths at the most. The leaves have therefore, in this instance, acted as a true sieve.

The same effect is produced by the foliage of all plants and trees, but it must be borne in mind that to obtain this result three conditions are necessary. 1st. The plants must receive the direct action of the sun. 2nd. The surrounding temperature must not be lower than 50° to $53\frac{1}{2}^{\circ}$ F. 3rd. The plants must not be stripped of their leaves.

The absence of either of these three conditions would stop the phenomenon and tend to render the plants inert. When deprived of light, leaves, instead of absorbing carbonic dioxide and setting free oxygen, absorb oxygen and set free carbonic dioxide in their ordinary respiration process.

Lastly, I would add that the leaves are essentially the seat of the assimilation of carbon; neither the roots, nor the trunk, nor the branches participating in this important function.

We will pass to considerations of a more practical nature, and more nearly allied to agriculture.

The quantity of carbon which plants absorb in the course of a season may reach to nearly 4 tons per acre.

But all plants are not equally favoured in this respect on account of the difference in the surfaces of their leaves: moreover they differ in their power of carbon fixation for the same area of leaf surface. If, for instance, we compare wheat, Jerusalem artichokes, beetroot, potatoes, &c., we find in the case of the Jerusalem artichoke, which fixes 3 tons 4 cwt. of

carbon per acre, that the surface of the leaves represents fifteen times that of the soil cultivated. Beetroot, which absorbs only 16 cwts. of carbon,¹ presents a surface of leaves not more than five times that of the soil. The same observations apply to the potato and also to wheat, which absorb respectively only 1,496 lbs. and 1,232 lbs. of carbon per acre, and whose leaves present a still more reduced surface.

To complete the study of the assimilation of carbon, it is only necessary to say that if the atmosphere is the principal source from which plants derive their supply of this element, they nevertheless draw a certain quantity from the deeper layers of the soil, the carbonic dioxide contained in which is absorbed by the roots, and afterwards decomposed by the leaves into oxygen and carbon, the latter element being assimilated. The carbonic dioxide of the soil is formed by the decomposition of vegetable detritus. The mode by which carbon is absorbed by plants may be summed up in three facts, viz. :—

(1) It is always absorbed in the state of carbonic dioxide.

(2) The green leaves effect the decomposition of the carbonic dioxide.

(3) The solar rays are the active agents in causing the leaves to effect this decomposition.

Oxygen and Hydrogen.

As far as the source of oxygen and hydrogen is concerned, plants receive more of these elements from rain than they can utilise.

It may perhaps be asked if it is quite certain that the oxygen and hydrogen have their origin in water. This may be proved by attempting to cultivate plants in calcined sand: the plants during their growth receive oxygen and hydrogen only in the form of distilled water, yet the water in some way undergoes change and enters into the composition of plants.

Nitrogen.

Nitrogen is assimilated by plants in several different forms, but chiefly :—

As the nitrate of some base.

As nitrogen gas.

One or other of these forms is found specially suited to certain kinds of plants, for instance, nitrogen enters as nitrates

¹ The figures here given are deduced from the returns obtained at the farm of Bechelbronn. Having regard to the smallness of these returns, the data mentioned must be considered as the *minima*.

into beetroot, wheat and most farm crops, while leguminous plants absorb it in the form of free gas.

It has been ascertained that crops always contain more nitrogen than the manure supplied to them.

Boussingault, for instance, has shown that in the case of lucern there is an increase during growth amounting to 150 lbs. per acre.

This excess of nitrogen is derived, not from the soil, but from the air; but the question now arises, In what state has the nitrogen been absorbed? Is it in the state of nitrates, or of free nitrogen?

There is no doubt that the air contains both ammonia and nitrates, but only in infinitesimal quantities. The proportion of ammonia is between 0.000000017 and 0.000000032, or from 17 to 32 lbs. of ammonia to 1,000 million lbs. of air, and the proportion of nitric acid is scarcely equal to that of ammonia.

In face of these minute quantities, it is evident that the enormous amount of nitrogen cannot be attributed to them. Rain-water contains on an average half a pound, in a million pounds, of ammonia, and the same of nitric acid. Now, these quantities represent a contribution only of $5\frac{1}{2}$ lbs. of nitrogen per acre annually, which is evidently insufficient to explain the excess of 150 lbs. in the case of lucern.

We are thus led to attribute to the free nitrogen of the air the excess which otherwise would remain unexplained.

Now, if the nitrogen is assimilated in lucern only in the state of nitrate, we ought evidently to find in the crop a certain amount of the bases corresponding to the nitric acid, the supposed source of nitrogen. None, however, are found to exist. In a crop of lucern grown in the field at Vincennes, there was a quantity of nitrogen amounting to 119 lbs. per acre, which, from the absence of the corresponding bases, could not possibly have penetrated into the plant in the state of nitrate. This 119 lbs. is only a third part of the actual quantity of nitrogen that an acre of lucern absorbs from the air, for in the case I have named, nitrogen, in the forms of potassic and sodic nitrates, had intentionally been introduced into the manure, and it has since been proved that yields quite as large can be obtained by substituting potassic carbonate for the nitrates.

I will suppose that sodic nitrate is used as manure for peas, trefoil or lucern. This is attended with no specially good results. To illustrate the fact that they can do without it we will institute two parallel experiments. In one the grounds should receive a dressing composed of calcic phosphate potash and lime without nitrogen. In the other nitrogenous matter

must be added to those three agents. Under these two conditions very different effects will take place according to the nature of the plants. Trefoil, peas and leguminous plants thrive quite as well in the land which has received no nitrogenous matter as on any other. With wheat, colza, beetroot and tobacco, the results would be quite different. Where the nitrogenous matter is absent the yields would be very moderate, whilst it would be greatly increased in the ground which had been dressed with it.

It may be concluded from this that plants form two totally distinct groups, the one comprising those which absorb their nitrogen from the soil as nitrates, the other those which obtain it from free nitrogen of the air.

It is well known that crops without manure become very scanty, but the yield is never absolutely *nil*, and the quantity of nitrogen corresponding to it is still sufficiently considerable; it would, in fact, according to Messrs. Lawes and Gilbert, rise to—

Wheat	.	.	.	$24\frac{1}{2}$	lbs. per acre.
Barley	.	.	.	$23\frac{3}{4}$	„
Grass	.	.	.	$38\frac{3}{4}$	„
Beans	.	.	.	$46\frac{1}{2}$	„

From this table it will be seen that grass land and beans absorb more nitrogen than barley and wheat. Can it be said that the nitrogen of the beans and grass comes from the soil? This gives rise to another difficulty. If we sow wheat after beans the yield is larger and the quantity of nitrogen fixed is greater; but on the other hand we have just said that beans contain more nitrogen than wheat! Is it not evident that if they had taken it from the earth the yield of wheat would have been affected by it?

To conclude—nitrogen is absorbed under different forms. For leguminous plants free nitrogen is the most suitable; for wheat, colza and beetroot, nitrates. But when the crop shows an excess of nitrogen, neither the manures nor the soil can account for it—it can only be due to the free nitrogen of the air.

I will sum up this question by some indisputable figures designed to fix with precision the quantities of nitrogen that various plants obtain from the soil and the air:—

Per acre	Excess of nitrogen in crops over that furnished by the manure		
Wheat	.	.	$52\frac{3}{4}$ lbs.
Peas	.	.	$61\frac{1}{2}$ „
Colza	.	.	$114\frac{1}{2}$ „
Beetroot	.	.	$114\frac{1}{2}$ „
Lucern	.	.	264 „

In these examples the manure contained from 44 to $52\frac{3}{4}$ lbs. of nitrogen per acre for lucern. I took the excess from a purely chemical manure and from a yield fixed at 3 tons 2 cwts. These examples prove, then, that if all plants show an excess of nitrogen, that excess is far greater in some than in others. There is still one distinction to be made with respect to the condition under which it is produced.

There are indeed some plants the crops of which contain a great deal of nitrogen without it having been furnished at all by manures. For example, peas, beans, trefoil and lucern. There are others also which show a considerable excess of nitrogen, such as beetroot and colza, but only on the express condition of having received nitrogenous manures; lastly, there is a third class of plants which require a great deal of nitrogen in the soil and of which the crop gives only a relatively slight excess; an instance of this occurs in the case of wheat.¹

These differences are so important in practice that they cannot be overlooked. There must be a great advantage both with respect to the crops and the improvement of the soil in alternating wheat with beetroot and leguminous plants, that is to say, the plants which obtain their nitrogen from the soil with those which obtain it from the air.

These conjectures are fully confirmed by experience. Wheat grown in succession to clover yields a larger crop than that which preceded it, and it is a well-known fact that beetroot leaves dug into the soil greatly favour the cultivation of wheat.

But with regard to those plants which, like beetroot, require large quantities of nitrogen in the manure, there is yet one important remark to be made, viz., that the excess of nitrogen in the crop is in some sort proportional to the quantity received by the soil.

It follows from this that the most improving methods of culture are not those which require the least nitrogenous

¹ It is now a well-established fact that leguminous plants are able to obtain very considerable quantities of free nitrogen from the air by means of the bacteria in their root nodules; other plants such as the cereals and roots, are not able to do this, hence the great difference between crops in their nitrogen content when grown under conditions where the soil supplies little or no combined nitrogen.

The fixation of free nitrogen also takes place in the soil through the activity of various bacterial organisms. Comparatively small amounts are added in this way, but whatever is added may be taken up eventually by cereal and other crops, so that these may sometimes show an excess of nitrogen over that supplied in the soil and manure.

manure to ensure fertility, but those in which the greatest excess of nitrogen is employed, an excess which is supplied by the atmosphere alone. This connection and mutual dependence between the richness of the manure and the decided improvement in the plant which has received it, a connection of which science furnishes the true explanation, has long since been verified in practice, as will be seen from the following observations of Mathieu de Dombasle:—

“It is a generally observed fact,” he says, “that the functions by which plants appropriate the nutritive elements contained in the soil and in the air are *corresponding functions*, so that an increase in the quantity of the active principles which they draw from the earth will ensure a still larger quantity of atmospheric nutrition. *It is for this reason that those plants which improve most rapidly, that is to say, which take most from the air, make still greater improvement when grown in a more fertile soil.*”

This theory of high cultivation may be explained in a more striking and scientific manner. Let us take for instance a plant cultivated in calcined sand, depending for its nourishment upon air and water alone, and producing in the first five days of germination twenty leaves. If the part played by a leaf in the nutrition of a plant results in the production of a new leaf every fifteen days, at the end of three and a half months the plant will have produced 2,560 leaves.

Suppose, on the other hand, another plant cultivated in a manured soil, and admit that the effect of the manure will be the production of five fresh leaves every fortnight in addition to those which were formed when air and water were its only food. After the same lapse of time the plant will have produced 3,195 leaves, or nearly one and a half times as many as in the first case, and yet the manure applied to the soil has by itself resulted in the formation of only thirty-five leaves. This result, which we may consider rather extraordinary, is, however, explained very easily if we consider that the first leaves, which owe their origin to the manure, assist in the increase of the crop, not only by their number, but also by the leaves subsequently formed, of which they are the beginning and which owe their subsequent nourishment solely to the atmosphere.

I have said that it is necessary to vary the quantity of nitrogenous manure according to the nature of the crop to be grown. I will now give the yields which a distinguished agriculturist, M. Cavallier, has obtained at the farm of Mesnil-Saint-Nicaise.

The case is one in which beetroot was grown under four

different conditions: with chemical manure without nitrogen, and with the same manure to which were added increasing quantities of ammoniac sulphate.

	Roots, tons per acre	
	Tons	Cwts.
With chemical manure without nitrogen the yield was	14	14
Same manure with 176 lbs. of nitrogenous manure (ammonium sulphate)	19	0
Same manure with 220 lbs. of nitrogenous manure (ammonium sulphate)	20	8
Same manure with 264 lbs. of nitrogenous manure (ammonium sulphate)	23	16

If we take as the starting-point the yield of 14 tons 14 cwts. obtained by manure without nitrogen, we shall find that, the price of ammoniac sulphate being subtracted, there remains a surplus of profit.

Increased Profit.

	£	s.	d.
With 176 lbs. of nitrogenous manure (ammonium sulphate)	2	14	2
„ 220 „ „ „	4	6	8
„ 264 „ „ „	9	2	6

It is thus seen that nitrogenous matter plays a most important part in plant economy. In practice it is found a great advantage to employ ammoniacal salts and sodic nitrate; the fixity of their composition, the certainty of their action, and their ready assimilation giving to them a marked superiority over all other nitrogenous compounds.

I have been in the habit of employing these products in quantities of from 53 to 80 lbs. of nitrogen per acre¹ for wheat, for colza and beetroot from 88 to 105 lbs. per acre² can be used without inconvenience. It may be added that ammoniac sulphate contains in round numbers 20 per cent. of nitrogen and sodic nitrate 15 per cent.

As these products are endowed with great power, we cannot be too careful in distributing them equally; this may be easily effected by mixing them with four or five times their weight of fine and dry earth. When this has been done, the mixture is spread on the land after the ploughing is completed. It is afterwards harrowed to ensure their mixture with the surface soil.

¹ 265 to 400 lbs. sulphate of ammonia or 353 to 553 lbs. nitrate of soda.

² 440 to 525 lbs. sulphate of ammonia or 586 to 700 lbs. nitrate of soda.

These are very heavy doses: half these amounts are more economical and what the author frequently used in his practice.

If we reflect on the foregoing ideas we shall find that between the carbon, hydrogen and oxygen on the one part, and the nitrogen on the other, there is, from an agricultural point of view, this great difference—that nature always provides plants with a superabundance of the three first, while she only furnishes nitrogen exceptionally and under certain conditions. The secret of good farming consists in alternating those plants which derive nitrogen from the air with those which obtain it from the soil, and taking care to supply the latter with manures composed of nitrogenous compounds.

The nitrates and the ammoniacal salts are not the only nitrogenous compounds to which we can have recourse. Animal matter can also be employed, provided that it enters readily into a state of putrefaction, when it acts like ammoniacal salts, the nitrogen becoming finally transformed into nitrates.

I, however, prefer the latter, because they are directly assimilable, and also because that for every 100 parts of nitrogen, which the organic matter contains, there are at least 30 parts lost to vegetation. This loss is the result of the decomposition to which these matters are subjected, 30 per cent. of the total nitrogen being evolved in the state of free gas, in which form the atmosphere contains more than vegetation is able to utilise.

It cannot be too often repeated that it is one of the secrets of profitable farming, to draw from the air as much nitrogen as possible by the alternation of crops. All the efforts of agriculturists must be directed to this end, and one of the most valuable services rendered to agriculture by science has been the setting forth of this fact.

If science is a guide which must sometimes be followed with reserve on account of the financial questions with which agricultural operations are complicated and sometimes impeded, it must not be forgotten that all that has been done in agriculture is in conformity with its laws, and that if we are on the eve of seeing improvements accomplished superior to all that has been done in the past, it is to science that our thanks will be due.

In the next lecture we shall treat of the function of mineral matter in the economy of plant production.

LECTURE III.

MINERAL MATTER IN MANURES—NORMAL MANURE—MECHANICAL CONSTITUENTS OF SOIL—HUMUS AS A FERTILISER—TESTING RICHNESS OF SOIL.

THE inorganic elements ordinarily entering into the composition of plants are ten in number, viz., phosphorus, sulphur, chlorine, silicon, calcium, magnesium, potassium, sodium, iron, and possibly manganese. But it is a surprising fact that we are almost entirely ignorant of the state in which they enter into the organisation of vegetable tissues. We know that it is in the form of chemical compounds, but we cannot exactly determine their nature and composition. Our imperfect knowledge in this respect will be less astonishing if I add that, to acquire the slightest notion of their presence, we usually begin by burning the tissues which contain them.

But if science presents in this respect a gap that is to be regretted, we know at least with certainty in what form, and under what conditions, minerals may become extremely efficacious in agriculture as fertilising agents. If the inorganic element in question is phosphorus, it is in the state of calcic phosphate that it must be employed ; if it is potassium, in the state of carbonate, nitrate or silicate, and in the case of calcium in that of carbonate or sulphate.¹ This second point, which is more important than the first, viz., the most favourable form in which to employ the inorganic elements, in order to ensure good results, is then quite settled. But here an unexpected question presents itself.

I have just said that ten different inorganic or mineral elements enter into the composition of plants, and now I am obliged to add that with the help of nitrogenous matter, three only are sufficient to increase and maintain the fertility of the soil, and that the agriculturist need not concern himself about the remaining seven.

It must not, however, be thought that the latter have no effect on plants. They are no less necessary than the three

¹ The author seems to imply that calcium present as phosphate is not utilised. Subsequently he admits, however, the value of calcium nitrate.

first, and if they can be practically dispensed with in artificial manures, it is only because the worst soils are superabundantly provided with them.¹

If the observations I have just made are correct, the conclusion is obvious. It ought to be possible by their aid to obtain as luxuriant a growth in calcined sand, which is inert in itself, as in the most fertile alluvial soil. All that is necessary for this is a due proportion of the ten inorganic elements and of nitrogenous matter.

It follows equally from these fundamental data, that in natural soil the same result may be obtained with a nitrogenous material and three compounds only, calcic phosphate, potash, and lime. These two theoretical principles are confirmed by experience.

We may follow this order of ideas still further. If it be true that each inorganic element plays a part peculiar to itself, and that the beneficial effect of the whole is to a certain extent dependent upon the presence of each of these elements in particular, we ought, by the suppression of one or more components of the fertilising mixture, to be able to form a series of gradations progressing from the most precarious to

¹ I may be allowed, *à propos* of the composition of normal manure, to reproduce the declaration I made in my fifth Conference at Vincennes :—

“In limiting the composition of normal manure to calcic phosphate, potash, lime and nitrogenous matter, I do not intend to deny the utility of the other products which analysis shows to be present in plants. I suppress them only because the soil is already sufficiently provided with them.

“It may be that more efficacious compounds of iron and manganese exist than those which the soil contains naturally, and whose presence in manures would be followed by an increased yield. When experience has proved the correctness of this principle we shall zealously conform to its prescriptions. But till then we shall persist in excluding from normal manure any additions the value of which has not been fully proved.

“Science is not immutable. Quite the contrary. There are some few primary facts which have become established laws, but the interpretations of secondary facts are changing incessantly, in proportion as their number increases, and as the conditions of their manifestation are better known. No one can pretend to be possessed of every scientific fact and principle connected with vegetation. In the transition state through which we are passing, the wisest course is to rely on the testimony of facts, neither neglecting their teaching nor going beyond it, and above all to avoid fixed ideas. Faithful to this principle, which it has always been our aim to follow, let us compose a manure which may be as readily perfected as the science which teaches us its composition. Let us content ourselves with combining those products whose action is at present well defined, and whose most servicable form is thoroughly understood. Such a manure will be the most perfect that can be obtained in the present stage of our knowledge. It will suffice for all practical requirements, and if the future reveals useful additions to it, we can at least affirm that nothing will have to be taken away.”

the most abundant crop. This new principle is also borne out by experience. But as a question of great importance is here at stake, and in order that our results may be beyond dispute, let us work out these suppositions in a soil composed of calcined sand, in the composition of which there is nothing that is not definitely known.

In calcined sand, without any addition, but soaked with distilled water, wheat acquires only a rudimentary development, the straw being hardly as large as a knitting-needle. Under these conditions, however, vegetation follows its ordinary course, the plant blossoms and bears seed, but in each ear there are only one or two small and imperfectly developed grains. Thus in a soil as barren as can possibly be, wheat finds in the water with which it is irrigated, in the carbonic dioxide of the air, together with the small store of food in the grain sown, means whereby it can perform the entire cycle of its evolution, though of course in a feeble manner.

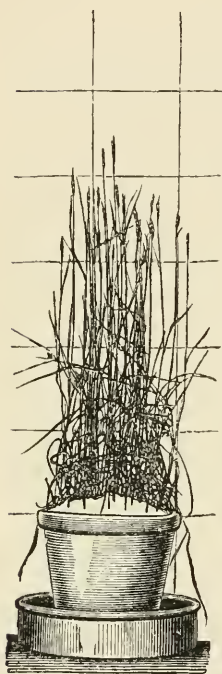


FIG. 1.

With twenty-two seeds of wheat weighing about fifteen grains in weight, a crop weighing over ninety grains is obtained (Fig. 1). Add to the calcined sand the ten inorganic elements, excluding nitrogenous matter, and the result is scarcely, if any, better. Under these new conditions the corn is rather more developed than in the former case, but the crop is still very feeble, amounting only to about 123 grains (Fig. 2). Reversing this second experiment, we leave

out all the mineral matter and add a nitrogenous matter only to the sand (Fig. 3). The vegetation still remains very poor and stunted; the yield, however, is somewhat larger, amounting to about 138 grains. The gradually increasing yield should be carefully noted. In pure calcined sand the yield was 92 grains; with the mineral matter, but without nitrogenous matter, 123 grains; with nitrogenous matter, 138 grains. In the last case a fresh phenomenon is developed. As long as we use mineral matter alone, the plants are etiolated, and the leaves are of a yellowish-green colour; but as soon as a nitrogenous matter is added to the sand, the

leaves change their hue and become dark green, and it seems as if the vegetation was about to assume its ordinary vigour; it is, however, only a deceitful appearance, for the crop remains as poor as ever.

Up to the present time we have not exceeded the most rudimentary returns; we will now try a fourth experiment, which is, in some sort, the synthesis of the three preceding ones. We will add to the calcined sand both the mineral and nitrogenous matter. The result is almost magical, so greatly

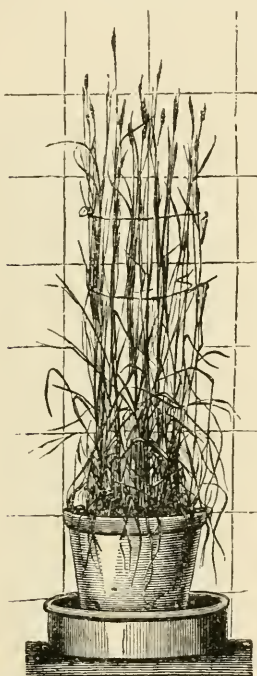


FIG. 2.

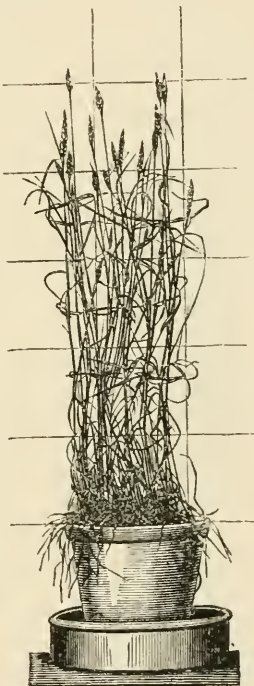


FIG. 3.

does this phenomenon contrast with those that have gone before. Previously the growths were languishing, precarious and etiolated; but now the plants spring up rather than grow, the leaves are beautifully green, the stem, straight and firm, terminating in an ear filled with good grains, and the harvest weighs from 327 to 383 grains (Fig. 4).

We have thus succeeded in producing plants artificially without using farmyard manure or any unknown substance. You will agree with me that this is an important funda-

mental point. There is no mystery or undetermined force; a few chemical products of definite purity, some distilled water, perfectly pure in itself, a few seeds to start with, and the result is a crop that will in every respect bear comparison with those obtained on thoroughly good soil.

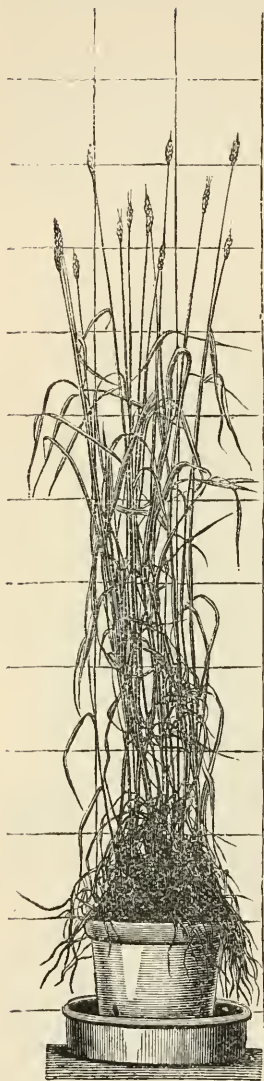


FIG. 4.

We are consequently justified in saying that the problem of vegetation has here received its absolute solution, for we have not only defined the conditions that govern the production of plants, but also the degree of importance of each of the agents that contribute to it. Thus the nitrogenous matter produces by itself alone a greater effect than all the mineral matters put together. But a good crop is not obtained until these two kinds of matters are united.

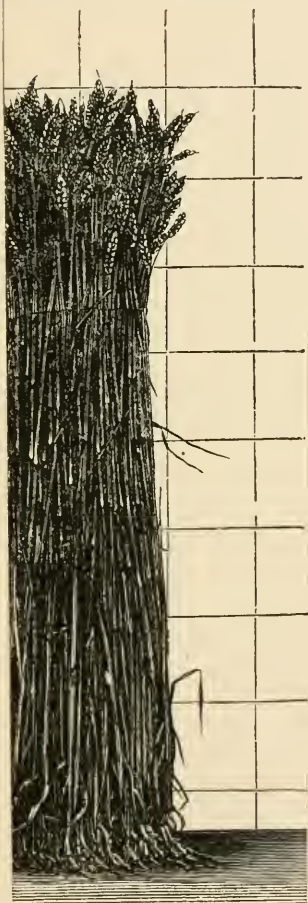
I will again remark, that in passing from calcined sands to natural soils, the number of inorganic elements used as manure may be reduced from ten to three without inconvenience. If under these new conditions two parallel experiments are made, the one with a nitrogenous matter and all the ten inorganic elements, and the other with a nitrogenous material and three mineral substances only, viz., calcic phosphate, potash and lime, the yields will be equal.

In calcined sand this abstraction of seven elements would render vegetation impossible; but as such curtailment is not injurious in natural soils, it is manifest that these seven elements exist in them.

The conditions most favourable to fertility consist therefore in the union of these four substances: *nitrogenous matter, calcic phosphate, potash and lime*: and I have therefore given this mixture the name of normal manure.

ST OF 1863.

URE WITHOUT NITROGENOUS
MATTER.



ELD PER ACRE.

	lbs.	Bushels
. .	2,643	
. .	1,132	18
	<hr/> 3,775	

NORMAL MANURE.

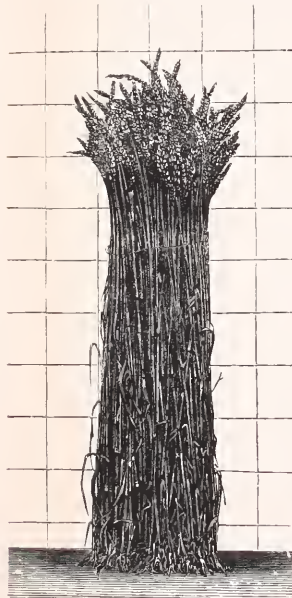


YIELD PER ACRE.

	lbs.	Bushels
Straw . . .	6,108	
Grain . . .	3,300	50½
	<u>9,408</u>	

EXPERIMENTAL FIELD AT VINCENNES.—HARVEST OF 1863.

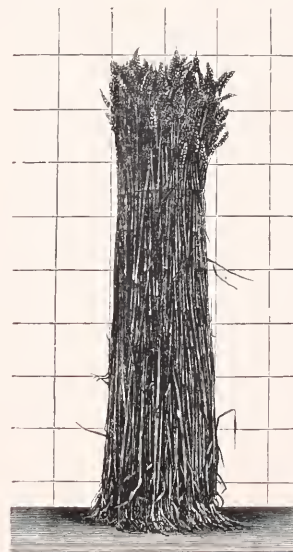
NITROGENOUS MANURE WITHOUT MINERAL MATTER.



YIELD PER ACRE.

	lbs.	Bushels
Straw . . .	3,069	
Grain . . .	1,426	22
	<u>4,495</u>	

CHEMICAL MANURE WITHOUT NITROGENOUS MATTER.



YIELD PER ACRE.

	lbs.	Bushels
Straw . . .	2,643	
Grain . . .	1,132	18
	<u>3,775</u>	

WITHOUT ANY MANURE.



YIELD PER ACRE.

	lbs.	Bushels
Straw . . .	2,323	
Grain . . .	794	12
	<u>3,117</u>	

In order to confirm what I have just said, I will place before you a series of crops grown in the open air with chemical manures only. (Plate 1.) The inequalities seen in them are occasioned by nothing else than by leaving out one of the four substances composing the normal manure, so true is it that the union of the four is indispensable in order to obtain luxuriant crops. Although the ten elements of which we have just been speaking alone participate in the production of plants, yet in order to play their part, these elements require the assistance of another class of substances, which the soil also contains, and of which we will now speak.

These substances, which are three in number, namely, clay, sand and humus, differ from the preceding elements, inasmuch as the part they play is purely passive. They serve, in fact, as a support to plants, but do not by themselves contribute to the maintenance of plant life. To distinguish them from the first, which are called *assimilable constituents* of the soil, these have received the name of *mechanical constituents*.

But this is not all: the assimilable constituents are themselves divided into two groups, the active assimilable constituents and the assimilable constituents in reserve, so called because they cannot contribute to the production of vegetation until they have undergone a preliminary decomposition, by which means the plant is enabled to absorb them. A single example will be sufficient to point out the necessity for this distinction.

Nitrogenous matters of animal origin produce, on being decomposed, ammonia and nitrates, and to that formation they owe their useful effect; the excreta and skins of animals are a case in point, as they are speedily decomposed with great readiness.

But if the skin is submitted to the process of tanning, by which it is transformed into leather, it is decomposed with extreme slowness and difficulty, thus losing a part of its immediate activity.

In the first case skins belong to the group of active assimilable constituents, while in the second instance they enter into the group of assimilable constituents in reserve.

Now there are in the soil organic and inorganic products which, like the last example, do not exercise any useful action until they have undergone a preliminary decomposition produced more or less slowly. It is then necessary to mark the distinction between these two states of assimilable constituents.

Thus clay has the power of absorbing and retaining a great deal of water, a most important property, since it pre-

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serves a sufficient amount of humidity in the soil, without which vegetation would become impossible. But in time clay will dry up and harden when it is exposed to the action of the sun: it then becomes so compact that the roots of plants cannot penetrate it. In this case sand, which by itself is unsuitable for vegetation, because it forms too shifting a soil, and one which is moreover incapable of retaining water, intervenes most opportunely. Formed of isolated grains perfectly independent of each other, sand, when mixed with the clay, diminishes its compactness and communicates to it the character of a porous and mobile medium, as permeable to the air as to water—a condition essential to vegetable life.

Clay possesses another property worthy of remark—that of fixing in the soil the nitrogenous and mineral matters by which its fertility is essentially determined. This fixation is not complete and definite, it is only in a manner superficial and transitory, for in the end the clay gives back to vegetation the active principles of which it seemed to have obtained possession.

To enable the character of this property to be clearly comprehended I will give an example:—

If a piece of clay be steeped in liquid muck, the liquid is decolourised, and an analysis shows that at the end of a certain period it has lost a part of the ammonia as well as some salts which it hitherto contained. Let us then reverse the experiment. Steep the same clay in distilled water, and it will, little by little, yield up the products which it had extracted from the liquid muck. Finally, if the active principles of the soil are not drawn off by the rain-water, it is again owing to the clay, which, in addition to the property of retaining the fertilising principles of the soil, also unites that of afterwards regulating their solution.

The absorbent property possessed by clay is more or less great in proportion as the solutions upon which it acts are more or less concentrated. In a solution containing four per cent. of potash or ammonia, the clay absorbs more of these two alkalies than in a solution containing only one or two per cent. of them. Hence it follows that if periods of drought occur, the only thing to be feared is that the soluble part of the soil may acquire a degree of concentration which is dangerous to the plants; but the clay prevents this. If a prolonged rainfall occurs the clay yields to the water the substances which it had previously absorbed. It follows from these actions and reactions that clay acts on the assimilable elements of the soil as a sort of regulating material, retaining or yielding them by turns as the earth passes from a state of

drought to one of excessive humidity. It is clear then that although clay and sand do not contribute directly to plant growth, they fulfil a most important office.

Before leaving this point I will say a word on the nature of these two bodies. Clay is a hydrated aluminic silicate, in which the proportion of water is very uncertain, seeing that it varies from ten to twenty per cent. of its weight. Clay has its origin in the silicates of eruptive rocks. It is perhaps difficult to believe that granite and porphyry, which are considered as symbolical of resistance and hardness, alter with astonishing facility. When the cooling of these rocks has taken place too quickly they undergo, by the action of time, a sort of internal exfoliation, after which their alkaline and earthy bases—potash, lime, &c.—are dissolved out by the action of rain-water, whilst the alumina remaining in combination with a part of the silica forms the clay with which we are so familiar.

Sand is of a much more simple nature: it is essentially formed of silica in the state of quartz, and belongs to the great family of sandstone rocks, which themselves have their origin in the eruptive or volcanic rocks which have been carried away and pulverised by the action of water. Thus clay owes its origin to the chemical decomposition of these rocks, and sand to their trituration, resulting from their being displaced by the action of water. An example of this is found in the alluvial soils found by our rivers.

The soil contains another substance which is very different from the preceding ones, viz., "humus," to which agriculturists have hitherto wrongly attributed a very important function.¹

Heath mould, which is formed principally of sand, contains a black substance, which is insoluble in water, but is soluble in a solution of caustic potash. This black substance, which is also found in farmyard manure, and in most natural soils in very unequal proportions, is humus. Its composition is doubtful, but it is supposed to contain carbon combined with hydrogen and oxygen in the proportions requisite to form water, and according to this view it enters into the category of the carbo-hydrates, cellulose, sugar, starch, &c., which represent ninety-five per cent. of the weight of plants.

Humus has its origin in the actual substance of plants, which, by a kind of spontaneous decomposition, has lost a certain quantity of hydrogen and oxygen in the form of water.

I have said that many intelligent men place humus in the foremost rank as a fertilising agent, but if we ask them for

¹ Liebig, nearly half a century ago, proved that humus could not be regarded as a plant-food.

proofs in support of their opinion, they are not forthcoming. Plant nutrition is an extremely complex phenomenon, the thorough investigation of which can scarcely be traced back for twenty years. When sufficient data were wanting to explain, hypotheses and words supplied their place. Humus had the honour of serving as an explanation for everything that could not be understood. Thanks to this concurrence in explanation, men appeared to agree upon the subject, when in reality they were far from doing so.

Faithful to our programme, we will try to avoid this snare. Let us lay aside words and go to the root of the matter, gaining our light and information from experience. How, and under what circumstances, does humus act favourably?

The first of its good effects is, that like clay it possesses the property of absorbing a great deal of water, thus contributing to the maintenance of humidity in the soil. If, however, we remember that the soil contains only a very small percentage of humus, it is very difficult to allow that such small quantities have the power of modifying the physical condition of the soil.

Humus possesses a most useful property, that of fixing the ammonia in the soil so as to prevent it from being carried off by the rains. It afterwards gives back this ammonia to vegetation. Its functions in this respect are analogous to those of clay. Up to the present these functions have not appeared very important, but now the utility of humus begins to be evident. It absorbs the oxygen of the air, and afterwards undergoes a slow, inappreciable, but real combustion. It thus becomes the source of a gradual, but uninterrupted formation in the soil of carbonic dioxide, which is less useful on account of the carbon it furnishes to vegetation than for the solvent power which it exercises with regard to certain minerals, and especially calcic phosphate and limestone.

We shall prove the truth of this fact by a very simple experiment.

Grow two plants in calcined sand, one with the aid of humus, and the other without, giving to both the same quantity of chemical manure. In both cases the yield will be exactly the same, but analysis will show that there is more calcic phosphate in the crop obtained by the help of humus than in that grown in the sand alone. Humus therefore helps to supply the plants with phosphate.

Humus can in certain cases produce a still more useful effect, for in a measure it increases the yield. This happens when the humus is associated with calcic phosphate.

To prove this we will make four fresh experiments. In the first place we will grow some plants in calcined sand, the soil being provided with nitrogenous matter, and all the necessary mineral matters which must be employed in these conditions with the exception of calcic carbonate. If twenty-two grains of wheat are sown, the crop will weigh from 307 to 337 grains. This yield is not altered by adding humus. Add humus to the sand, and the crop does not change. Substitute calcic carbonate for humus, and still there is no change. Add at the same time both humus and calcic carbonate and the yield is increased in weight to 475 grains. These facts being practically of fundamental importance, I subjoin the following table:—

	Nature of soil		Yield Grains
1. Normal manure . . .	Calcined sand . . .		337
2. „ . . .	Limed sand . . .		337
3. „ . . .	Sand and humus . . .		337
4. „ . . .	Sand with lime and humus		475

The increase in the yield obtained in the last case is due to the combined action of the humus and calcic carbonate. But what is the cause of this favourable action of humus? Is it by reason of its absorbing power? No. Its rôle is limited to assisting in the solution of the calcic carbonate, and to prove this we have only to make a fifth experiment in which the calcic carbonate and humus are replaced by calcic sulphate, or better still by calcic nitrate, which is far more soluble, when we shall again obtain a yield of 475 grains. It is unnecessary to add that when calcic nitrate is employed, we take into consideration the nitrogen that it contains, and that it is reckoned in the sum of the nitrogenous matter. It is thus proved by unimpeachable experiments that the good effects of the humus are due in this case to its solvent action on the calcic carbonate, which is proved by its being found possible to arrive at the same result by the aid of a salt of lime more soluble than the carbonate. I will even add that it was this that decided me to substitute calcic sulphate for the carbonate in the manufacture of normal manure.

But it will be said—these are laboratory experiments, and in the matters of cultivation it is always dangerous to accept such testimony. You may ask me to give you proofs obtained from cultivation on a large scale. I am happy to be able to furnish you with them.

On some land in Champagne, tilled for the first time with 32 tons of farmyard manure per acre, 14 bushels of wheat were obtained, while with normal manure the yield rose to 36 bushels. On an acre of silicious earth in the Department

of the Aisne, with 16 tons of farmyard manure, $8\frac{3}{4}$ bushels of wheat were obtained; but with the chemical manure the yield was increased to 31 bushels per acre. The same land, without being manured at all, produced $2\frac{3}{4}$ bushels. Finally, in the Department of the Drome, on a stony hillside cleared for the express purpose, the land without manure yielded $3\frac{1}{4}$ bushels per acre; manured with $15\frac{1}{2}$ tons per acre of farmyard manure, it produced 9 bushels per acre, and with normal chemical manure the yield was 33 bushels per acre.

M. Payen in the Department of the Aisne, M. de Matharel in the Department of the Oise, and M. le Chevalier Mussa in Italy, obtained similar results. In the case of some fields chosen from among the poorest land, where a large quantity of farmyard manure only produced from 9 to 11 bushels per acre, the use of chemical manure increased the yield from $27\frac{1}{2}$ to 33 bushels per acre. Now, if we observe that in these experiments, in which the land was of very inferior quality, manure which contained compounds analogous to humus proved to be much less efficacious than chemical manure, it is clear that we can, strictly speaking, do without humus and still obtain very fine crops. A small number of experiments will thus have served to define the functions of all the fertilising agents which the soil ought to contain, or with which it must be provided by means of manure.

It might be believed that chemical analysis, which has done so much in our time, and which has attained such a high degree both of delicacy and certainty, ought to enable us to test with certainty the richness of the soil, and by so doing to serve as a guide in the choice of manures best suited to its nature. It is not so, however, and I defy the cleverest chemist to tell beforehand what will be the yield of any land submitted to him, and what manure ought to be used.

A few words will explain why chemistry is powerless to furnish these indications. We must here call to mind the distinction which we have allowed to exist between the different constituents of which the soil is composed.

Let us suppose some land containing amongst its mechanical elements quartzose and felspathic sand. For plants these two sands are equally valuable, although the first is silica only, while the second is a silicate with a lime, potash and soda base, containing also small but very appreciable quantities of calcic phosphate.

Here, then, are two bodies whose composition, notwithstanding their outward similitude, is not at all analogous; yet they are of equal value from an agricultural point of view, because the felspathic sand being insoluble in water, the part

it plays with respect to vegetation descends to the rank of that of quartzose sand, that is to say, that of a simple mechanical material. But for the chemist there are no insoluble bodies, so he ranks the potash, lime and calcic phosphate contained in the felspathic sand, and which are of no use in increasing vegetation, in the same category with the products of a similar nature which we have arranged in the class of active assimilable agents.

This shows the insufficiency of the information we receive from chemistry alone.

We have in the case of the Vincennes land a striking proof of the dangers of this confusion by which we may too often be led astray. According to an analysis of this land, made by me with the greatest care, I found that in over 400,000 tons of soil, which about represent the weight of the vegetable mould distributed over the surface of an acre, there was—

	Tons Cwts.	
Phosphoric acid	0	14 per acre
Potash	0	18 „
Lime	15	15 „

This constitutes a considerable amount of fertility. Now if corn were to be grown on this land for four successive years, a nitrogenous material being used for manure, the yield at the end of the fourth year would be not more than $5\frac{1}{2}$ to $6\frac{1}{2}$ bushels per acre.

The soil therefore shows a great scarcity of mineral matter, and these four crops take away from the soil only—

Phosphoric acid	75 lbs. per acre
Potash	81 „
Lime	35 „

These quantities are far removed from those indicated by chemical analysis. It may be said that there is a mistake in my analysis; but this is not so, for the soil indeed contains what I have quoted; but this indication can be of no practical utility to us, because in calculating the proportions of these inorganic elements, we have not distinguished between what are active and what are inert.¹

What use is it for us to have put ourselves to the trouble of discovering the elements to which plants owe their forma-

¹ Much of this difficulty may be got over by determining separately the potash, phosphoric acid, lime, &c, soluble in water or in vegetable acids.

The “available” or “active” fertilising constituents of the soil as distinct from the inert substances are approximately determined by Dyer’s method of extracting the soil with a weak solution (1 per cent.) of citric acid.

tion, and to define the conditions of their efficacy, if after all we are powerless to recognise their presence in the soil, in the special condition which assures that efficacy? Happily we are not in such a situation. We have other means of acquiring the information with which chemistry cannot furnish us, and these methods are not only within the reach of agriculturists, but enter in a measure into the routine of their daily labour.

I said in the last lecture that plants are divided into two classes. With reference to the different forms under which they assimilate nitrogen—some obtaining it from the air in the form of free nitrogen, while others derive it from the soil in the form of nitrates—you can appreciate the result of this distinction. Those plants which derive nitrogen from the air flourish exceedingly well in a soil which is destitute of that element as long as they find in it the three mineral constituents of the normal manure, potash, calcic phosphate and lime. Plants which derive nitrogen from the soil become, on the contrary, etiolated and yield only a scanty crop. It follows from this that by the aid of two experiments on a small scale we may always know if the land contains the necessary nitrogenous and mineral matter.

If we cultivate side by side peas and wheat, or peas and beetroot, and the peas yield well whilst the wheat turns out badly, we are able to conclude unhesitatingly that the land is provided with the mineral, but lacks the nitrogenous matter; on the other hand, if the wheat succeeds equally well, we may be certain that the land contains both the mineral and nitrogenous matter. Can you conceive a method which is more practical and yet at the same time simpler and more conclusive?

At Vincennes nothing succeeds in the land if we discontinue the use of manure, neither peas nor wheat nor beetroot will flourish—which proves that it is destitute both of nitrogen and the necessary mineral matter.

These indications, although very useful, are not, however, sufficient for all practical requirements in order to act with safety. We need more precise data with regard to the presence or absence in the soil of each constituent of the normal manure, that is to say, of potash, calcic phosphate and nitrogenous matter.

These new indications are as easy to obtain as the former, and in the following manner. Suppose we grow seven specimens of the same plant—beetroot or wheat, whichever we prefer. To the first we apply normal manure; to the second the same, but with the nitrogenous matter excluded;

to the third we apply normal manure, but with the calcic phosphate left out; to the fourth the normal manure without the potash; to the fifth the normal manure without lime; to the sixth nitrogenised manure from which all mineral matter is excluded; and to the seventh no manure at all.

It is very evident that if in the normal manure the proper effect of each ingredient is only manifested when it is combined with the other three, the comparison of the yields obtained on the seven allotments of the little field must indicate what the soil contains and what it lacks.

In this system of investigation the cultivation by means of normal manure becomes in some sort the invariable standard of comparison with which the yields of the other allotments must be compared, and as they approach or are distant from it, so the soil does or does not contain the element which has been purposely excluded from the manure.

In order to put the value of this method beyond doubt I will relate the results arrived at under three different conditions. In the experimental field at Vincennes we obtained with wheat in 1864 the following yields:—

	Bushels per acre
Normal manure . . .	43
Manure without lime . . .	41
„ potash . . .	31
„ phosphate . . .	26½
„ nitrogen . . .	14
With no manure . . .	12

The conclusion is evident. At Vincennes normal manure is needed. At the same time what is especially wanted in the soil is nitrogenous matter. An eminent agriculturist in the Department of the Somme has furnished me with my second example, which relates to beetroot:—

	Tons	Cwts.
Normal manure . . .	20	16
Manure without lime . . .	18	16
„ potash . . .	16	16
„ phosphate . . .	14	16
„ nitrogen . . .	14	8
With no manure . . .	10	0

Here, again, the soil is wanting in nitrogenous matter, and in order to put it in a fit state to obtain good crops we must have recourse to normal manure. This experiment was made at Mesnil-Saint-Nicaise by M. Cavallier. My third example is taken from an experiment on the cultivation of sugar-cane carried on at Guadeloupe by M. de Jabrun, an old settler in that colony:—

		Tons	Cwts.
Normal manure . . .	.	23	0
Manure without lime . . .	.	20	0
„ potash . . .	.	14	0
„ phosphate . . .	.	6	0
„ nitrogen . . .	.	22	8
With no manure . . .	.	1	4

If I add that the cane obtains its nitrogen from the air, you will conclude from these figures that the soil is very defective in potash and calcic phosphate. We have here, then, two methods of testing the richness of the land. The first is founded upon the cultivation of two different plants without any manure, and the second on the cultivation of the same plant with five different manures.

These two applications of the same principles lead to results which reciprocally verify and complete each other.

It is not necessary to add that for these trials to have their full value the experiments must be made when the last manure placed upon the land has become quite exhausted.

We have then not only determined all the elements which enter into the composition of plants, but we have also distinguished between those of which Nature offers to vegetation inexhaustible supplies and those which our industry must, on the contrary, furnish to the soil. Further, by the aid of our experiments in calcined sand and with chemical products only, we have realised a theoretical scale of culture, the progressive yields of which have demonstrated to us the laws which regulate plant growth. By the light of these discoveries we have been able to invent and to realise practical methods of analysis accessible to all, the proof of which is almost absolutely certain, and by means of which we may always know what the soil contains and in what it is deficient, thereby enabling us to determine the nature of the fertilising agents that must be employed.

In the next lecture we shall follow the results of these principles, giving special attention to the yields that may be obtained in practice by the aid of chemical manures.

LECTURE IV.

TYPICAL FERTILISERS—ADVANTAGES OF CHEMICAL MANURE—
FREE USE OF MANURE—CULTIVATION OF WHEAT—REGU-
LATION OF QUANTITY AND COMPOSITION OF MANURE FOR
ALTERNATE CROP OF COLZA AND WHEAT, FOR ROTATION OF
FOUR YEARS, FOR ROTATION OF SIX YEARS—SOURCES OF
POTASH, LIME AND NITROGEN.

If it be true that calcic phosphate, potash and lime, in combination with some sort of nitrogenous matter, form the essential constituents which produce plant life, farmyard manure, which till recent times has been the only means by which the farmer could keep up the fertility of the soil, ought necessarily to contain all these four ingredients.

Here are three analyses of farmyard manure. They fully bear out the proposition just laid down, for they show that nitrogen, phosphoric acid, potash and lime are all present :—

		In 100 parts of dry manure		
		From the farm at Vincennes	From the farm at Bechelbronn	From the farm at Thier-Garten (Bas-Rhin)
Organic Elements	{ Carbon . . . }	59.65	65.50	64.67
	{ Hydrogen . . }			
	{ Oxygen . . . }			
	{ Nitrogen . . . }	2.08	2.00	2.56
	{ Phosphoric acid . . }	0.88	1.00	1.26
Mineral Constituents	{ Sulphuric acid . . }	traces	0.63	0.82
	{ Chlorine . . . }	0.70	0.20	0.32
	{ Alumina, ferric oxide. }	0.68	2.03	1.51
	{ Lime . . . }	5.23	2.83	3.70
	{ Magnesia . . . }	0.32	1.20	1.88
	{ Soda . . . }	traces }	2.60	{ 0.87 3.87 6.25
	{ Potash . . . }	2.46 }		
	{ Soluble silica . . }	1.45 }		
	{ Sand . . . }	25.66 }	22.31	{ 10.77

This table shows that besides the four constituents which must necessarily form part of a normal manure, ordinary farmyard manure contains carbon, hydrogen and oxygen. But our knowledge of the origin of these three bodies will

have led us rightly to infer that their presence in manure does not in any way increase its value. The same remark applies to the sodic chloride, magnesia, soda, silica, ferric oxide, &c., contained in farmyard manure, which must be excluded from forming part of the normal manure, seeing that they are abundantly contained in the poorest soils.

Farmyard manure is therefore, so to speak, the incontestable type of a fertilising material, containing as it does the four constituents which are the foundation of plant growth, and consequently the only ones with which agricultural industry is in any way connected. I repeat that we have here an undeniable proof of the value of our previous inquiries. In order, however, that this proof should be complete and without question, the identity of result must be placed side by side with the identity of composition. In this respect practice once more confirms our theoretical information. With our normal manure the yield is always larger than when ordinary farmyard manure has been used. The value of these data is all the greater because they are founded on operations carried out on a large scale. I have obtained them from farmers, who, at my request, have been good enough to try certain experiments on the comparative value of artificial and farmyard manure. Throughout all these experiments the advantage has always been on the side of the former.

The first result which I shall point out to you is that which was obtained by M. Peyrat, the assistant manager of the Educational Farm, at Beyrie, in the Landes.

Three crops of beetroot were grown in ordinary soil; the first without any manure, the second with normal manure, and the third with 32 tons of farmyard dung.

	Roots per acre	
On unmanured land the yield was . . .	3 tons	5 cwts.
With 32 tons of farmyard manure it reached . . .	19 "	13 "
With chemical manure it amounted to . . .	21 "	4 "

The chemical manure, which was applied in the proportion of $13\frac{1}{2}$ cwts., was found to be superior to 32 tons of farmyard manure.

On the farm belonging to the Marquis de Verieue, in the department of the Isère, a similar result was arrived at:—

	Per acre
With 20 tons of farmyard manure the yield was	18 tons 14 cwts.
With $11\frac{1}{2}$ cwts. of chemical manure . . .	20 "

At M. Leroy's farm, at Varesnes (Oise), with $10\frac{1}{2}$ cwts. of chemical manure, the yield was 24 tons 18 cwts. per acre.

With 20 tons of farmyard manure supplemented by 6 cwts. of guano the yield only amounted to 16 tons per acre.

In the island of Guadeloupe, on one of the poorest soils of the colony, farmyard manure produced 12 tons 16 cwts. per acre, while chemical manure produced 22 tons 8 cwts., and unmanured land yielded only 1 ton 4 cwts. per acre.¹ These are significant facts, and, as I have already said, they have been communicated to me by eminently practical men, who are animated with a desire to progress, who work out the experiments without preconceived notions, and who at the present time are affording me the most valuable aid.

At M. Cavallier's farm, at Mesnil-Saint-Nicaise (Somme), with 20 tons per acre of farmyard manure applied to a field of beetroot, the yield was 14 tons per acre. With 15½ cwts. of chemical manure, the yield was 24 tons per acre.

The same results are obtained in the case of wheat and potatoes. At the farm of MM. Masson and Isarn at Evreux, chemical manure gave 44 bushels per acre, while 12 tons of farmyard manure only yielded 21 bushels per acre.

At M. Bravay's farm, in the department of the Drôme, on a piece of stony barren land, which was taken into cultivation for the purpose, the produce in the case of chemical manure was at the rate of 33 bushels per acre. With about 11½ tons of farmyard manure per acre, the yield was 12 bushels, and on unmanured land, 2¼ bushels, or about as much as the seed sown.

With wheat the most remarkable result is that obtained by M. Ponsard on an uncultivated piece of land in Champagne which was scarcely worth 2*l.* 15*s.* per acre, which yielded when sown with wheat:—

		Per acre
With 9½ cwts. of chemical manure	. .	36½ bushels
With 40 tons of farmyard manure	. .	14¼ „

M. Ponsard, in reporting the result of his experiments to me, writes:—

“The land upon which I experimented was a piece of waste ground which had never seen the plough, and which was barely worth 2*l.* 15*s.* per acre. Before the winter of 1865 had run out, the wheat sown was in full growth, and during the whole season it was always superior to the neighbouring crop, which was grown on farmyard manure. Being so strong, it ripened much earlier, which enabled me to reap it before the rainy weather set in. I was able to sell it as seed corn at a very high price, for it was of a very superior

¹ Apparently of sugar-cane.

quality. At the market rate the acre would have yielded as follows:—

With Chemical Manure.

	Per acre
	£ s. d.
1 ton of wheat, at 12s. 9 $\frac{3}{4}$ d. per cwt.	12 16 3
Cost of manure	5 2 6
Profit	£7 13 9

With Farmyard Manure.

40 tons of farmyard manure at 6s.	£12 0 0
8 cwt. of wheat at 12s. 9 $\frac{3}{4}$ d.	5 2 6
Loss	£6 17 6"

There is no need for me to remark that in this report M. Ponsard has not thought it necessary to go into detail, but has simply put forward the two results, which show a difference of some 11l. or 13l., or more than four times the value of the land. The crop grown by M. Ponsard is really so astonishing that it is difficult to believe. It will therefore be well if possible to confirm these data by analogous results, which will deprive them of the exceptional character which one is tempted to give them. For this purpose I quote the following results. Upon an acre of sandy soil of very inferior quality, M. Louis Payen obtained during the same year, 1865, with artificial manure:—

	Per acre
	£ s. d.
30 $\frac{3}{4}$ bushels of wheat at 7s. 10 $\frac{1}{2}$ d. (the current price)	12 2 1
2 tons 8 cwt. of straw at 1s. 9d. per cwt.	4 4 0
Chaff	0 1 5
	£16 7 6

while 15 tons of farmyard manure applied to the same land produced only:—

	Per acre
	£ s. d.
8 $\frac{3}{4}$ bushels of wheat at 7s. 10 $\frac{1}{2}$ d.	3 8 11
13 cwt. of straw at 1s. 9d. per cwt.	1 2 9
Chaff	0 0 6
	£4 12 2

The same soil without manure produced barely 3 bushels per acre. If it is necessary to add to M. Payen's testimony, I am enabled to do so through the kindness of M. de Matharel, Inspector-General of Finance. On July 26 he

wrote to me, that from a piece of land which had never produced anything but rye, he had obtained 28 bushels of wheat per acre.

Let us compare the four results :—

Culture of Wheat—Yield per Acre.

	M. Ponsard (Champagne)	M. Bravay (Drôme)	M. Payen (Aisne)	M. de Matharel (Puy de Dôme)
	Bushels	Bushels	Bushels	Bushels
Chemical manure .	36	33	31	28
Farmyard manure .	14	12	9	—
Without manure .	—	3	2 $\frac{3}{4}$	—

We have here four sets of results obtained in different parts of France, always on bad soil, which are so much alike that one might almost be taken for another.

The results obtained in the case of the potato are not less significant. At the farm of the Marquis d'Havrincourt, chemical manure produced 6 tons 8 cwts. per acre. With 13 tons 2 cwts. per acre of stable dung, only 3 tons 4 cwts. per acre were obtained. At Vincennes I myself obtained from 10 to 12 tons per acre.

M. Lavaux, at his farm at Choisy-le-Temple, on a piece of ground measuring 47 $\frac{1}{2}$ acres, obtained :—

	Per acre
First year, wheat . . .	44 bushels
Second year, colza . . .	36 „
Third year, wheat . . .	29 „

The third year the corn was lodged.

In 1867 the beetroot crops varied from 22 to 28 tons per acre, while with 16 tons per acre of farmyard manure the yield barely reached 14 tons per acre.

Taking the sugar-cane as our next example, M. de Jabrun in 1867 produced in the island of Guadeloupe :—

	Stripped canes
	Per acre
	Tons Cwts.
With chemical manure . . .	33 18
Farmyard manure . . .	24 18
No manure . . .	10 12

Our experiments are therefore unanimous in testifying to the value of growing alternate crops when farmyard manure is used; it remains to be seen whether we gain the same advantage by adopting the same system when we use chemical manure.

Wheat grown	Per acre
After peas, gave . . .	50½ bushels
„ beetroot, gave . . .	38½ „
„ wheat, gave . . .	36½ „

Chemical manures, therefore, act precisely the same in this respect as farmyard manure: we find that in spite of their general want of resemblance, they depend for their effect on the same course, in fact that they are the same in their nature.

We now come to a series of questions which, if possible, are more important than the preceding ones. In farming operations the source of profit lies in the abundance of manure, but when this manure is produced on the farm itself, it is not always available for use when it is required. The amount of manure produced on a farm depends on the system upon which it is managed, on the number of animals which graze on the land, the quantity of land devoted to pasture, and, lastly, on the amount of floating capital in the hands of the farmer.

It needs a great deal of time, prudence and judgment to change the whole system on which a farm is managed, so as to bring the production of cereals and manure into prominence.

With chemical manure, on the other hand, the farmer acquires almost perfect liberty of action, and is enabled to regulate the quantity to be used at will, his operations being only limited by the amount of capital at his disposal.

By the use of chemical manure he may, so to speak, almost in a single day pass from a precarious to a thoroughly trustworthy system of farming, and thereby obtain a large amount of profit as compared with his former mediocre gains.

It will be seen that this is the most important point connected with the agriculture of the future. As I have already said, in farming the profits obtained depend on the quantity of manure that is spread over the land. With a small amount of manure the crops are small, and the profit is nothing, if even there is not an absolute loss. With generous manuring the yield is increased, and the profit is certain, for the excess in expenditure is not more than one-half or one-third of the excess of the yield. To make this truth plainer, I may mention that the cultivation of the soil necessitates two kinds of expenditure. First of all, there are fixed expenses which never change, no matter whether we adopt a good or a bad system of farming, such as rent, taxes, rates, cost of seed, &c. Then come expenses which change according to circumstances, such as carting, threshing and manure. I hold, then, that the system of farming which is sparing in manure is always a losing speculation,

while with an abundant use of fertilising agents profit is certain.¹ How can it be otherwise, seeing that manure is the raw material from which our crops are produced. But these questions are of too serious a nature to be simply stated dogmatically. Let us analyse the facts, and examine the figures showing the amount of produce which is obtained as the result of so much expenditure, so as to leave no doubt upon this point.

I will take as an example the case of a piece of land yielding $14\frac{1}{2}$ bushels per acre, which is the average yield of French corn land. According to M. Mathieu de Dombasle, the minimum expenditure for such a yield is 4*l.* 14*s.* per acre, which is reduced to 3*l.* 18*s.* per acre by deducting the value of the straw, for $14\frac{1}{2}$ bushels, which makes the price per bushel 5*s.* 5*d.* nearly.

		£	s.	d.	£	s.	d.
Fixed expenses	{ Rent	0	14	5			
	{ General expenses	0	16	10			
	{ Farm labour	0	13	10			
	{ Seed	0	14	8	2	19	9
Variable expenses	{ Manure	1	3	8			
	{ Reaping, threshing, &c.	0	10	8	1	14	4
Total expenses					£4	14	1
Deduct for straw, say					0	16	0
Balance					£3	18	1

Suppose, that without in any way changing the system carried on at the farm of Rville, without changing the number of sheep and beasts, or altering the succession of the crops and the method of cultivation, we suddenly increased the expense for chemical manure by 1*l.* 18*s.* 4*d.* per acre, without increasing any of the other expenses, in this case we should find the yield would jump from $14\frac{1}{2}$ bushels to $34\frac{1}{2}$ bushels per acre, so that the cost of producing a bushel of corn would fall from 5*s.* 5*d.* to about 3*s.* 8*d.* for $34\frac{1}{2}$ bushels per acre.

		£	s.	d.	Per acre £ s. d.
Fixed expenses	{ As above				2 19 9
	{ Manure	3	2	1	
Variable expenses	{ Reaping, &c.	0	19	2	4 1 3
					£7 1 0
Deduct for straw					1 10 4
					£5 10 8

¹ It is scarcely necessary to add, "weather and vermin permitting".

I have already said that the superiority of this system of culture lies in the fact that any increase in the sums expended on manure is always less than the value of the increase in the crop. In the first case, where the yield was $14\frac{1}{2}$ bushels per acre, and the cost 5s. 5d. per bushel, if we fix the selling price at 6s. 5d. we shall find the crop represents a value of 4l. 13s. 0 $\frac{1}{2}$ d., or a profit of 14s. 11 $\frac{1}{2}$ d. per acre.

In the second case, with an increased expense of 1l. 18s. 5d., which is reduced by the increased value of the straw to 1l. 4s., the crop is worth 11l. 0s. 3 $\frac{2}{3}$ d., the profit per acre being 5l. 9s. 7 $\frac{2}{3}$ d. instead of 14s. 11 $\frac{1}{2}$ d.

There is another result derived from these too little known data, namely, that it is better to farm well on a small scale by being generous with our manure than to waste our effort over a large plot of land manured with parsimony. For instance, if a farmer has a capital of 1,200l., he will, by adopting the system carried out at Roville (where the expenses amount to 4l. 16s. per acre), be able to cultivate 250 acres, the result of which would be that he would gain :—

By straw, at 16s per acre.	£200
By corn, at 15·4 bushels per acre, <i>i.e.</i> , 3,850 bushels, and at a fraction less than 6s. 5d. per bushel	1,235
	<hr/> 1,435

the profit on the 1,200l. being therefore 235l.

With the same capital, by using chemical manure, he would reduce his land to 136 $\frac{1}{2}$ acres, but these 136 $\frac{1}{2}$ acres would yield him 1,569l. 0s. 1d. instead of 1,435l.

In other words he would gain :—

	£	s.	d.
By straw, at a fraction over 1l. 10s. 4d. per acre	207	0	6
By wheat, at the rate of 31·1 bushels per acre for 136 $\frac{1}{2}$ acres, <i>i.e.</i> , 4,245·15 bushels at a little less than 6s. 5d. per bushel.	1,361	19	8
	<hr/> £1,569	0	2

or a profit of 369l. instead of 235l.

These are no rash innovations or revolutionary proceedings, but actual improvements, the benefits of which are felt daily by practical men. I maintain that corn may be grown at from 3s. 2d. to 3s. 4d. per bushel. If this is a revolution, at least it is one about the reality of which there is no dispute, a revolution which must in time be accomplished, because truth always triumphs over routine and its prejudices.

After having made clear the more immediate results that may be expected from the use of chemical manures, I will

justify these facts by the exactness of my calculations. I will take for my first example the continuous cultivation of wheat.

In a period of four years there have been obtained from a certain field an average yield at the rate of 2 tons of straw per acre and 34 bushels of corn. I specially call attention to these results, because it will enable me to point out certain dangers with respect to the loss of nitrogenous matters. When relying upon my laboratory studies, I began to make experiments in open-air cultivation at Vincennes; and having only my theoretical views to guide me, I asked myself first of all how long a certain amount of chemical manure applied to a field of a certain size would last.

The chemical manure experimented upon was used in the following proportions :—

Calcic phosphate	352 lbs. per acre
Potash	111 "
Lime	264 "
Sal ammoniac	572 "

representing 149 lbs. of nitrogen per acre.

The land was delivered to me too late to be sown with autumn wheat: I had, therefore, to sow it with March wheat. The wheat grew most luxuriantly, so much so that a great deal of it was lodged, the crop being thereby injured. Nevertheless, after everything had been taken into consideration, the yield was at the rate of 34 bushels of wheat and 1 ton 14 cwts. of straw per acre.

The next year the same accident occurred through a still more luxuriant growth, and the wheat lodging still earlier, the yield was correspondingly diminished, falling to 26 bushels of wheat and to 1 ton 11 cwts. of straw per acre.

The third year autumn wheat was sown instead of March wheat, and the whole aspect of affairs changed. This time the growth of the wheat was most luxuriant, and the yield reached 53 bushels of wheat and 2 tons 15 cwts. of straw per acre. Finally, the fourth year there was obtained 26 bushels of wheat and 1 ton 16 cwts. of straw per acre.

The whole of the four crops amounted to :—

Wheat	139 bushels
Straw	7 tons 16 cwts.

Or a mean of

Wheat	34 $\frac{1}{2}$ bushels per acre
Straw	1 ton 19 cwts. per acre

Two conclusions may be drawn from this experiment. The first is that for wheat we must not use our nitrogenous material in too large a proportion at once *i.e.*, at the rate of 150 lbs. per acre. Unless this rule be attended to, accidents are sure to occur. If the corn escapes being lodged it is rarely free from smut, and even if both these evils are avoided the straw grows so fast that the yield of wheat is interfered with.

As a general rule it is much better to divide our nitrogenous material into two portions, one-half to be used in autumn and the other in spring, but always as top-dressing. The first should be used when the wheat is about 4 or 5 inches high, the second in spring, from the 10th to the 30th of March. It is hardly necessary to observe that the second portion of ammoniac sulphate need only be used should occasion require it. Six times out of ten a dressing of from 48 to 96 lbs. per acre in the spring will be sufficient.

The Autumn Cultivation of Wheat.

	Per acre lbs.	£	s.	d.
Normal manure, No. 1 A, 528 lbs.				
Calcic super-phosphate . . .	176	0	7	8
{ Potassic chloride at 80° . . .	88	0	6	5
{ Ammonic sulphate . . .	171	1	11	2
Calcic sulphate, <i>i.e.</i> , gypsum . . .	93	0	0	8
		2	5	11

In the Spring.

Ammonic sulphate, 44, 88, or 132 lbs. per acre	1	4	0
	3	9	11

On condition that these dressings are repeated yearly an average yield is obtained of 33 bushels of wheat per acre, at a maximum expenditure of 3*l.* 9*s.* 11*d.* per acre.

For an alternate crop of colza and wheat I should recommend the following:—

First Year.

COLZA.

	Per acre lbs.	Price £ s. d.
Normal manure, No. 1, 1,056 lbs.		
Calcic super-phosphate . . .	352	0 15 4
Potassic nitrate . . .	176	1 18 5
Ammonic sulphate . . .	220	2 0 0
Calcic sulphate . . .	308	0 2 3
		4 16 0

Second Year.

WHEAT.

Ammonic sulphate	264	2	8	0
Ashes of haulm and pods of colza	nil		nil	
<hr/>				
Total expenses		7	4	0
„ per annum, say		3	12	0

In this case we begin the rotation with the colza, which must be kept clear of weeds. After the crop has been gathered the pods and haulm of the colza are burnt on the spot and ploughed in, so that the soil may lose as little of its potash and calcic phosphate as possible. A dressing of ammonic sulphate is given in the spring.

I now pass on to a rotation of four years, which is greatly approved of by practical men, as it has the merit of substituting alternate and continuous rotation for triennial rotation. It is carried out according to the following plan:—First year, potatoes; second year, wheat; third year, clover; fourth year, wheat. The following are the manures to be used:—

First Year.

POTATOES.

	Per acre lbs.	Price £ s. d.
Normal manure, No. 3, 880 lbs.		
Calcic super-phosphate	352	0 15 4
Potassic nitrate	264	2 17 7
Calcic sulphate	264	0 2 0
		<hr/>
		3 14 11

Second Year.

WHEAT.

Ammonic sulphate	264	2	8	0
<hr/>				
6 2 11				

Third Year.

CLOVER.

Incomplete manure, No. 6, 880 lbs.				
Calcic super-phosphate	352	0	15	4
Potassic chloride at 80°	176	0	12	10
Calcic sulphate	352	0	2	8
<hr/>				
7 13 9				

Fourth Year.

WHEAT.

Ammonic sulphate	264	2	8	0
Total expenses		10	1	9
„ per annum		2	10	10

For a rotation lasting four years, and including beetroot, wheat, clover and wheat, we must replace the manures given above by the following:—

First Year.

BEETROOT.

	Per acre lbs.	Price £ s. d.		
Normal manure, No. 2, 1,056 lbs.				
Calcic super-phosphate	352	0	15	4
Potassic nitrate	176	1	18	5
Sodic nitrate	264	1	13	7
Calcic sulphate	264	0	2	0
		4	9	4

Second Year.

WHEAT.

Ammonic sulphate	264	2	8	0
		6	17	4

Third Year.

CLOVER.

Incomplete manure, ¹ No. 6	880	1	10	10
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Fourth Year.

WHEAT.

Ammonic sulphate	264	2	8	0
Total expenses		10	16	2
„ per annum		2	14	1

I now pass to a more complex system of rotation, extending as it does over five years. It includes potatoes, wheat, clover, colza and wheat.

First Year.

POTATOES.

	Per acre lbs.	Price £ s. d.		
Normal manure, ² No. 3	880	3	14	11

¹ For composition, see p. 51. ² For composition, see p. 51.

Second Year.

WHEAT.

Ammonic sulphate	264	2	8	0
		6	2	11

Third Year.

CLOVER.

Incomplete manure, ¹ No. 6	880	1	10	10
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Fourth Year.

COLZA.

Ammonic sulphate	352	3	4	0
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Fifth Year.

WHEAT.

Ammonic sulphate	264	2	8	0
Ashes of haulm and pods of colza	<i>nil</i>	<i>nil</i>		
Total expenses		13	5	9
„ per annum		2	13	2

To show how very important it is that we should regulate the quantity of manure to be employed according to the nature of the plants, I will give the results of the experiments made by M. Cavallier with progressive quantities of ammonic sulphate so applied as to give from 70 to 105 lbs. of nitrogen per acre, the proportions of the other ingredients of the manure being unaltered. The following are the results obtained:—

		Roots per acre	
		Tons	Cwts.
Without nitrogen		14	14
With 352 lbs. of ammonic sulphate		19	0
„ 444 „ „		20	8
„ 572 „ „		23	16

It will be noticed that the progressive increase in the yield corresponds exactly with increase in the quantity of nitrogenous material.

The manure reduced to its simple mineral salts and containing no nitrogenous matter, but only calcic phosphate, potash, and lime, produced 14 tons 14 cwts. of beetroot per acre. Now, if we take this yield as our starting-point, we shall find that the excess in the various crops caused by the increase in the quantity of ammonic sulphate shows an in-

¹ For composition, see p. 51.

crease of profit in proportion to the increase in the amount which was used.

With 352 lbs. of ammonic sulphate ¹ the profit was	£	s.	d.	
„ 440 lbs. it was	1	1	8	per acre
„ 572 „ „	1	14	6	„
„ 572 „ „	3	17	6	„

These results, which I borrow from one of the most distinguished agriculturists of the department of the Somme, show:—

(1) That beetroot requires a large quantity of nitrogenous matter.

(2) That as far as 112 lbs. of nitrogen per acre the profit is in proportion to the amount of ammonic sulphate used.

ROTATION OF SIX YEARS.

FLAX, BEETROOTS, WHEAT, COLZA, WHEAT, OATS, RYE, OR BARLEY.

First Year.

FLAX.²

	Per acre lbs.	Price £ s. d.
Normal manure, No. 6, 880 lbs.		
Calcic super-phosphate . . .	352	0 15 4
Potassic nitrate . . .	176	1 18 5
Calcic sulphate . . .	352	0 2 8
		<hr/>
		2 16 5

Second Year.

BEETROOT.

Normal manure, ³ No. 2 . . .	1,056	4 9 4
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Third Year.

WHEAT.

Ammonic sulphate	264	2 8 0
----------------------------	-----	-------

¹ When these experiments were made ammonic sulphate was worth about 1*l.* 8*s.* per cwt.

² The following letter, relating to the effects of this manure upon flax, has been received by me:—

“Although my flax was sown only on May 10, in ground prepared with chemical manure, it grew so beautifully, both as to size and fineness, and took such a good colour when it ripened, that I sold it all standing, the buyer paying all expenses, at about 14*l.* 14*s.* per acre. When I sowed it on May 10, I was far from expecting such a result, knowing that the land was only moderately fertile.

(Signed)

“CHAVÉE,

“Clermont les Fermes

“(Aisne), 1867.”

³ For composition, see p. 52.

Fourth Year.

COLZA.

Normal manure, ¹ No. 1	. . .	1,056	4	16	0
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Fifth Year.

WHEAT.

Ashes of colza ploughed in first year	. . .	<i>nil</i>	<i>nil</i>		
Ammonic sulphate	. . .	264	2	8	0

Sixth Year.

OATS, BARLEY, OR RYE.

Ammonic sulphate	. . .	176	1	12	0
Total expenses	. . .		18	9	9
„ per annum	. . .		3	1	10

This succession of crops, treated as I have indicated, always gives magnificent results.

I will finish these directions by giving a receipt for two manures which I think are the most fitted for lucern and the vine.

Manure for Lucern for One Year.

	lbs.	Price £ s. d.
Incomplete manure, ² No. 6	. . . 880	1 10 10

Manure for the Vine for Two Years.

Normal manure, No. 4, 1,320 lbs.					
Calcic super-phosphate	. . .	528	0	17	0
Potassic nitrate	. . .	440	4	16	0
Calcic sulphate	. . .	352	0	2	8
Total expenses	. . .		5	15	8
„ per annum	. . .		2	17	10

At the experimental field at Vincennes I have, for the last two years, found it more advantageous to manure the vine every year, and for this purpose I use, of normal manure No. 3,³ 880 lbs. per acre. With this manure the crop increased from 1,056 lbs. to 1,232 lbs. per acre, equal to about 100 gallons of wine.

Great attention should be paid to the manner of using chemical manures. Farmyard manure may be distributed

¹ For composition, see p. 50.

² For composition, see p. 51.

³ For composition, see p. 52.

unevenly without much inconvenience, provided the irregularity is not pushed too far; but with chemical manures, on the contrary, any irregularity in the distribution is sure to endanger the welfare of the crop. This part of the work must, therefore, be attended to with particular care. Distribution by a machine satisfies all necessary conditions. When, however, we do not happen to have a machine at our disposal, the best thing to do is to mix the artificial manure with two or three times its bulk of mould, and distribute the mixture broadcast between the last ploughing and harrowing. The addition of the mould balances the effect of unequal distribution. This method of distribution is, it is true, more expensive than any other, but any extra outlay is amply compensated by the increased yield. When the operation is effectively performed, each acre produces two or three additional bushels, in other words, an increase in expenditure of from 1s. 8d. to 2s. is accompanied by an increase of produce amounting to 18s. 10d. In this case care is true economy.

Another question now presents itself which was treated of in great detail by me in the lectures I delivered in 1864. Not being able to deny the results of which I have given you an account, because too many agriculturists have verified them, certain persons have made the following objection to me:—

“Chemical manures,” they say, “are only a precarious resource; as soon as their use becomes general, their exorbitantly high price will render it impossible to employ them.”¹ A few summary explanations will, I hope, be sufficient to answer this last objection.

We will inquire into the natural sources of supply of the four ingredients in the normal manure about which I have spoken.

Taking calcic phosphate first, we shall find that twenty years ago the only known source of this compound was the bones of animals. It is certain that if we were to be reduced to this source of supply, its use could never become general. But at the present time there is no longer any danger of scarcity, for we know that calcic phosphate enters into the composition of all eruptive rocks, and that inexhaustible supplies of this mineral exist in various countries. In Estremadura in Spain, for instance, in the neighbourhood of Logrosan, there are eight or ten veins extending over a space

¹ All artificial manures are in fact used now in greater quantity, and are considerably cheaper than when the author delivered these lectures.

of several square kilomètres, and containing 70 to 85 per cent. of calcic phosphate. In Canada, Sweden, Russia and Central France there are also large deposits of this valuable substance.

In most marls we also find calcic phosphate. Below the cretaceous strata in the departments of the Ardennes and the Moselle deposits of this kind are found, the exhaustion of which has become part of the regular industry of this locality. This phosphate, though not so rich as the Estremadura deposit, contains from 16 to 18 per cent. of phosphoric acid. As far then as phosphates go, there is no need for anxiety, for their price is more likely to fall than rise.

The principal sources of potash are three in number.

1. The eruptive rocks, which constitute entire chains of mountains, and which often contain as much as 15 per cent. of that alkali.¹

2. Sea-water, from which we may extract potash with the greatest ease by employing the processes invented by the late M. Balard, and which alone would suffice for all our wants.

3. The deposits discovered at Stassfurth in Prussia some fifteen or sixteen years ago. These deposits are practically inexhaustible, being from 200 to 250 feet thick, and covering an area the extent of which has not yet been determined. They are connected with a formation of rock salt which leads one to think that similar discoveries will be made where similar geological conditions exist, more especially as geologists in other localities are on the look-out for such beds. It is not, therefore, to be supposed that this deposit in Prussia is an exceptional and isolated case. But even if similar discoveries do not take place elsewhere, the Stassfurth beds will be sufficient to supply our wants for many centuries to come, and even after they have become exhausted, we still have the mountains and the sea to fall back upon.

With regard to nitrogenous matter, I must admit that if we were to be obliged to employ no other sources of nitrogen than ammoniacal compounds and the nitrates, it might be held with a certain show of reason that at a given period the present known sources of these salts would prove to be insufficient; to the already known sources, however, others will no doubt be added. I may, for instance, refer to the manufacture of coke, which is now burnt in the open air.

¹ Orthoclase may contain 16 per cent. of potash, but the richest granite does not contain more than 45 per cent. of orthoclase, bringing the potash down to, say, 8 per cent. at the utmost.

It is only necessary to carry on this operation in closed furnaces to obtain large quantities of ammonia.¹

But even if all these sources were to fail, we should still have the nitrogen of the air, a point to which my attention has long been directed.

I have already said that there are certain plants which take their supply of nitrogen from the air, while others draw it from the earth. We can therefore by aid of the former come to the assistance of the latter.

This process is already applied in agriculture. The green manures are used on this principle, and their use ought to be made much more general, and plants which take their nitrogen from the air ought to be much more widely grown for this purpose than they are. Lucern, for instance, takes from the air from 264 to 352 lbs. of nitrogen per acre, which would be sufficient to supply at least four times as much land on which wheat is grown. If, therefore, all other sources of nitrogenous matter were to become exhausted, we should always have the nitrogen of the air, which may be easily gathered by plants themselves. But this is an extreme supposition. When humanity sets itself the task of solving a problem, that problem is certain to be solved.

The air being an inexhaustible source of nitrogen, what are we to do to procure from it inexhaustible supplies of ammonia and the nitrates? We must discover a process for cheaply combining the nitrogen with the oxygen of the air to form nitrates, or with hydrogen to form ammonia. This process has already been discovered. MM. Sourdeval and Margueritte have devised a method of converting the nitrogen of the air into nitrates or ammonia at will. If this process has not yet been adopted on a manufacturing scale, it is because from an economical point of view it does not satisfy all the conditions for working it easily. The principle, however, is known, and a second progressive step may, from one moment to another, make the solution of the problem complete.²

The supply of lime, it is well known, is utterly inexhaustible.

In former lectures we defined—by the aid of experiments which were more scientific than practical—the conditions which regulate the production of plants. In the present lecture, passing into the domain of practice, by examining

¹ Ammonium sulphate is obtained as a bye-product in various manufactures, *e.g.*, in gas works, shale and iron works, bone distilleries and coke ovens.

² The fixation of atmospheric nitrogen is discussed in a subsequent chapter.

into the traditions of fifty centuries, that is to say, into the composition of farmyard manure, we have sought to justify our choice of those substances which in our eyes are the symbols of fertility.

The proof has been in our favour. Manure contains these substances, and it is to them that its value is owing. To this testimony we wished to add another; we have submitted the question of the comparative worth of farmyard manure and chemical manures to a number of practical farmers; their experiments proved that the latter were superior. From these results we have drawn the conclusion that the principles which guide us are incontestable, and that it only remains for us to make this application general.

LECTURE V.

DOMINANT CONSTITUENTS IN MANURE—COST OF FARMYARD MANURE—COST OF CHEMICAL MANURE—GENEROUS USE OF MANURE—COMBINATION OF MANURES.

IN practice it is considered that the application of 16 tons of farmyard manure per acre every two years is sufficient for all ordinary purposes. Our aim on the present occasion being to compare farmyard manure with chemical manures, we will first inquire what are the proportions of the four ingredients which enter into the composition of our normal manure, in the 16 tons of farmyard manure. The following table gives the reply, being the mean of manures used at Bechelbronn and at the farm at Vincennes :—

	lbs.
Nitrogen	144
Phosphoric acid	66
Potash	132
Lime	282
Total	624 per acre.

If it be true, as experience seems to indicate, that farmyard manure owes all its efficiency to those four substances, its active portion is reduced to less than a fortieth of the whole mass. In ordinary manure there is 80 per cent. of moisture, which reduces the solid constituents of the 16 tons to 3 tons 4 cwts., in which latter figures we must count the carbo-hydrates, whose utility is more than problematical, at from 2 tons 8 cwts. to 2 tons 16 cwts. With 2,248 lbs. of chemical products we may compound a manure which is equal in richness to the 16 tons of farmyard manure. The following table will show the truth of this :—

	lbs. per acre
Calcic superphosphate	528
Potassic chloride }	282
Ammonic sulphate }	691
Calcic sulphate	747
Total	2,248

It is evident that with regard to the facility of distribution, cheapness of carriage, &c., the advantage is on the side of the chemical manure. This, however, is only a secondary matter. Their true superiority is due to other causes, and is justified by other considerations.

In ordinary manure the nitrogen is not always in a favourable condition for assimilation. The contrary is the case with the chemical manures. In farmyard manure the nitrogen exists in the excreta and in half-decomposed straw, &c., which cannot act favourably on the plants grown until after they have undergone a process of decomposition, which completely changes its condition. Nitrogen can only be assimilated after it has been transformed into ammonia or a nitrate. This previous decomposition, therefore, has for its chief result the loss of from 30 to 40 per cent. of the nitrogen which the manure originally contained, which escapes into the air in the elementary form. In the case of chemical manures, I repeat that the whole of the nitrogen may be assimilated direct, and that its action is thus rendered more certain.

The following is another practical advantage which is still more important. In the formulæ for chemical manures which I gave in my last lecture the nature of the ingredients varied according to that of the plants. The apportioning of each of them to certain categories of plants was not an arbitrary act, nor yet the result of fancy: it was simply in accordance with an important principle, the application of which is calculated to improve the quality of chemical manures. If it be true that a mixture of calcic phosphate, potash, lime and a certain amount of nitrogenous matter is sufficient for all the wants of plants, and may therefore take the place of farmyard manure in farming, it is no less true that each of these constituents, with regard to the three others, fulfils functions that are in turn subordinate or predominant according to the nature of the plants to be grown. Thus in the case of wheat, colza, beetroot and tobacco, the nitrogenous matter is the predominant ingredient; while for lucern, peas, haricots and horse beans, potash plays the most important part. For turnips, swedes, sugar-cane, maize and Jerusalem artichokes, calcic phosphate takes the most prominent position. There is, therefore, for every description of plant one substance which predominates over the three others, which may for that reason be called its dominant constituent.

To show the application of this principle we will suppose a field planted with the following rotation of crops—beetroot,

wheat, clover and oats. With farmyard manure there is no possible division. We cannot alter the composition, we can only vary the dose.

There are then only two courses open to us, viz., either to put all the manure on during the first year, or to distribute it over a longer period. In the first case we obtain a fine crop of beetroot, but to the prejudice of the succeeding crops. If we spread the operation over several years the yield of beetroot is greatly reduced, and as this kind of crop is very costly, owing to the amount of care and labour it requires, it must necessarily subject the farmer to loss. With chemical manures the case is very different. We give to each plant the substance which is most necessary for its growth, by which we gain the double advantage of reducing our expenses, and at the same time obtaining the most abundant crops possible under the circumstances. As a proof of the advantages to be gained in practice by this mode of procedure, I will give an example in the form of two crops of potatoes, followed by two crops of wheat grown side by side—one pair being manured with our normal manure, the whole being applied during the first year; the second with the same manure, applied in the following manner:—First year with mineral matter only; second year with nitrogenous matter.

First Case.—The field received the whole of the normal manure during the first year.

		Per acre				
		Tons	Cwts.			
First Year—Potatoes	.	10	4	.	£	s. d.
Second Year—Wheat	{ straw	2	1	.	3	6 4
	{ grain		18 = 34 bushels	.	9	18 3
Total		.	.	.	£23	8 0

Second Case.—The field manured the first year with mineral manure, and the second with 264 lbs. of ammoniac sulphate.

		Per acre		Value		
		Tons	Cwts.			
First Year—Potatoes	.	9	11	.	£	s. d.
Second Year—Wheat	{ straw	3	8	.	5	8 8
	{ grain	1	7 = 49½ bushels	.	14	8 1
Total		.	.	.	£29	7 0

The advantages gained by dividing the manure being thus placed beyond question, it will be easily understood that with a definite system of rotation I do not use the ingredients of the normal manure indifferently, but according to the nature of the crops. Supposing we grow four crops in the following

order—beetroot, wheat, clover and oats—we must concentrate the nitrogenous matter on the beetroot and the wheat, and the mineral matter on the clover, which itself leaves sufficient nitrogenous matter in the ground for the wants of the oat crop. Supposing the series to begin with a crop of peas or haricots, followed by wheat, clover and wheat a second time—the predominant needs of the haricots and the clover being mineral salts, while that of the wheat nitrogenous matter—we confine ourselves to applying the mineral salts to the land during the first and third years, while we reserve the nitrogenous salts for the wheat, using it during the second and fourth years. We must be careful, however, to give the wheat crop a good dose of nitrogenous matter during the second year. The fourth year the quantity may be reduced, the clover, the third crop of which is ploughed in green, being in itself a most efficient nitrogenous manure.

With what remarkable facility then can chemical manures be applied in practice to obtain maximum crops with the greatest amount of economy, allowing us as they do to concentrate on each crop the substances which are most necessary to its growth.

In my last lecture I confined myself to pointing out those facts without giving the reasons for them. On the present occasion I complete my first practical observations by giving you the theory which acts both as their basis and justification.

I will now pass on to a new question, which is no less important than the preceding one. I will inquire into the cost of farmyard manure as compared with chemical manure. It is not sufficient that the latter should be superior in its useful effects or in the greater facility with which it is applied: we must also take the economical view of the matter, and see, when accounts are balanced, whether the financial result is not also to the advantage of the chemical manure.

The question of the cost of farmyard manure is the one which has given rise to the greatest number of disputes amongst farmers. Every one estimates its price in his own way. There are even some who maintain that it costs nothing, others, on the contrary, maintain that it is a very dear commodity. It is necessary to decide which of these opinions contains the larger element of truth. I hope to be able to succeed by basing my observations on documents supplied to me by well-known farmers, whose trustworthiness is beyond question, and who have experimented under very different conditions. I am indebted for the first to M. Schattenmann, who obtained a grand prize at the Depart-

mental Exhibition of the Bas-Rhin in 1867, and another at the International Exhibition of the same year. I would only add that M. Schattenmann is a farmer of excellent position, who is placed under exceptionally favourable conditions for knowing the prime cost of everything, no matter how complicated it may be. According to the account with which he has furnished me, the production of 551 tons of farmyard manure and 300 tons of liquid muck did not cost less than about 603*l.*, which brings the price of farmyard manure to about 1*l.* 1*s.* per ton, if we take the cost of the liquid muck at about 1*s.* 8*d.* per ton. At M. Schattenmann's farm, in a carefully performed experiment, the farmyard manure was found to cost 1*l.* 1*s.* per ton. I must, however, remark that this price was the result of exceptional causes, and certainly exceeds the average of similar establishments. We will, however, take it as a starting-point:—

Cost of Farmyard Manure at the Thiergarten Farm (Bas-Rhin).

CHARGES.

	£	s.	d.
74 tons of straw for litter, at a fraction over 2 <i>l.</i> 9 <i>s.</i> 2 <i>d.</i> per ton	182	4	0
1,032 lbs. of liquid phosphoric acid, at rather under 1½ <i>d.</i> per lb.	5	18	2
Binding and carriage of straw for litter	4	0	0
2 tons 7cwts., nearly, coprolites, at about 2 <i>s.</i> 3 <i>d.</i> per cwt.	5	9	0
Emptying closets	0	8	0
Watering manure-heaps	2	3	0
Loading and carriage of manure	39	12	6
Filling barrels with liquid muck	2	6	6
Loss on beasts	137	17	5
„ cows	188	17	5
„ pigs	34	4	0
	603	0	0

PRODUCE.

300 tons of liquid muck, at 1 <i>s.</i> 8 <i>d.</i> per ton	25	0	0
551 tons of farmyard manure, at a little less than 21 <i>s.</i> per ton	578	0	0
	603	0	0

The second example was given to me by M. Cavallier, of the farm of Mesnil-Saint-Nicaise (Somme), but the conditions are very different. In M. Schattenmann's case it was a question of the production of manure in connection with all the details of a large farm, the price of the manure being influenced by the losses on the beast, cow and pig accounts. The document we have now under consideration is an account of a much more simple case, namely, the fattening of some 800 sheep. The following are the details:—

CHARGES.

	£	s.	d.
Cost of 800 sheep	784	0	0
300 tons of beetroot pulp, at a little over 9s. 7d. per ton . .	144	0	0
18 tons of rape cake	103	0	0
Colza haulm and rushes	54	0	0
Shepherds, yardmen, &c.	20	0	0
Interest, commission, &c.	10	0	0
	<hr/>		
	1,120	0	0

PRODUCE.

Sheep and wool	1,000	0	0
275 tons of manure, representing the balance	120	0	0
	<hr/>		
	1,120	0	0

This brings the price of the manure down to about 8s. 9d. per ton.

It must be remembered that this is not a general account in which each particular branch of the establishment has its influence, but is a special account, the result of which is independent of every other operation, in fact it is the fattening of 800 sheep on beetroot pulp, which is a cheaper food than ordinary forage. Under these favourable conditions the manure still costs about 8s. 9d. per ton.

M. Cavallier observes that if instead of having used colza haulm and rushes gathered from the ponds on the banks of the Somme, he had used wheat-straw, the manure would have cost him about 12s. 8d. per ton.

The third account which I shall take as an example is in connection with the farm of Bechelbronn, in Alsace, the details of which I extract from M. Boussingault's *Economie Rurale*. According to this calculation the manures would only cost about 4s. 2d. per ton, which seems to justify the opinion that farmyard manure is the cheapest and costs next to nothing; but on a little closer examination an objection arises which changes the whole aspect of the question, and which raises the cost of the manure from 4s. 2d. up to 11s. 10d. per ton.

How is it that with the same conditions we arrive at such different conclusions? The explanation is very simple, and I insist the more upon bringing it forward because it will furnish me at the same time with the opportunity and means of rectifying an error into which farmers too frequently fall in their system of book-keeping.

By a kind of tacit agreement, founded on the opinion that the production of manure is one of those necessities which cannot be done without, the food of the animals producing it is charged at its cost price and not at its sale price. Is not this a radically defective system to carry on?

When the farmer attaches a sugar-factory or distillery to his farm does he estimate the value of his beetroot at prime cost? No, he reckons them at the same price as those which he buys in the market. When he delivers his cattle and sheep does he give them at cost price? No, he is influenced by the condition of the market. To arrive at the true price of manure, it is absolutely necessary to adopt the system of dividing accounts, which is so advantageous to the trader by showing with certainty the origin of his profits, and by indicating where he ought specially to practise economy or spend more on means and appliances. In a properly conducted farm there should be a separate account opened for the stables, which should be credited with everything that fetches a real value, such as milk, butter, animals sold, increase of weight in the reserved animals, the work done by the horses; but, on the other hand the account should be debited with those expenses, of whatever nature, which have contributed to the realisation of the sums which have been carried to the credit side. In these expenses must be included the cost of keeping up the harness and waggons, the wages of the waggoners, shepherds, stable helps, &c., and, finally, this account must be debited with those commodities which are consumed by the animals at sale price, a deduction being made of from 10 to 15 per cent. as compensation for the cost of transport had they been sold off the premises. An account based on these data always shows a loss, but this loss is counterbalanced by the value of the manure produced. The loss divided by the number of tons of manure produced gives the price of the manure. If we alter the account given by M. Boussingault in the manner just described, we shall find that the price per ton of the manure is no longer 4s. 2d. per ton, but 11s. 10d. As this is a very serious question, I must be allowed to give you the account in two separate columns, one headed "arbitrary value," the other "real value".

Cost Price of Farmyard Manure at the Bechelbronn Farm.

	CHARGES.			Arbitrary value			Real value		
				£	s.	d.	£	s.	d.
162 tons 14 cwts. of hay after grass	.	.	.	234	5	2	363	14	3
56 tons 4 cwts. of dry clover	.	.	.	70	15	10	111	5	3
586 bushels of oats	.	.	.	38	13	7	72	16	10
29 tons 8 cwts. of potatoes	.	.	.	25	3	2	47	12	10
65 tons 8 cwts. of beetroot	.	.	.	31	18	3	37	13	7
12 bushels of peas	.	.	.	3	12	0	3	12	0
38 tons 10 cwts. of straw	.	.	.	19	4	10	55	8	10
				423	12	10	692	3	7
Repairing waggons and harness, and drivers' expenses	.	.	.	242	16	10	242	16	10
				666	9	8	935	0	5

PRODUCE.

	Arbitrary value			Real value		
	£	s.	d.	£	s.	d.
Increased weight of beasts, &c., 13 tons 10 cwts.	229	9	7	518	8	9
Milk not consumed on farm 28 tons 4 cwts.	135	7	2			
Increase in weight of pigs 2 tons 2 cwts.	50	8	0			
1,291 days of horse labour, at little more than 1s. 7d. a day	103	4	0			
Balance being loss	148	1	7	416	11	8
	666	10	4	935	0	5
Manure produced, 710 tons						
Cost 148l. 1s. 7d.				416	11	8
The price per ton being about 4s. 2d.				0	11	10

It must also be remembered that the true consumption of hay was not 162 tons 14 cwts., as given under the heading of arbitrary cost, but 183 tons 14 cwts.; this remark also applies to the item of oats, which ought to be increased from 586 bushels to 687 bushels.

It need hardly be said that the *arbitrary value* is that which is founded on the prime cost of the commodities, while the other is based on the selling price. Between these two there is a difference of 268l. 10s. 1d., which explains why in one case the manure is 4s. 2d. and in the other 11s. 10d. There is also no need to mention that in the two tables the loss in the year varies from 148l. 1s. 7d. to 416l. 12s. The quantity produced being 710 tons, 4s. 2d. and 11s. 10d. are the arbitrary and true prices respectively. I have already told you that the price 21s. at which M. Schattenmann arrived was an exception.

In fact, the farm in question being only recently established, the proprietors were obliged, to put it on the footing of an old concern, to buy immense quantities of straw in a year when that commodity was particularly dear. Having made this reservation, we may conclude from the figures given that the true price would be from 12s. to 16s. per ton. Let us put it at 12s. We will now speak of the price of chemical manures.

There are, we have already said, in 40 tons of manure—

Nitrogen	358½ lbs.
Phosphoric acid	165 "
Potash	330 "
Lime	706½ "

To obtain the equivalent of this manure in chemical substances we must have recourse to the following ingredients:—

	Quantity lbs.	Cost ¹ £ s. d.
Acid calcic phosphate . . .	1,320	2 17 6
{ Potassic chloride . . .	704	2 11 2
{ Ammonic sulphate . . .	1,727	15 13 11
Calcic sulphate . . .	1,870	0 13 6
		<hr/>
		£21 16 1

That is to say, 21*l.* 16*s.* 8*d.* for the equivalent of 40 tons of farmyard manure, which brings the cost of 1 ton to 10*s.* 11*d.*, the ton of farmyard manure costing 12*s.* It must also be remembered that the artificial equivalent of the 40 tons of manure contains 44 lbs. of phosphoric acid in addition. These are important conclusions. With chemical manures the yield is always greater, so that were they equal in price to farmyard manure, they are not so dear. The price of 12*s.* which I have adopted for farmyard manure will, it is said, fall lower. I may acknowledge at once that I am ignorant of the merits of this question, but that I do not think it will. The advantages of the use of artificial manure do not, however, end here. Putting aside for the moment all questions of profit and loss, let us see in what condition the farmer is who can only manure his land with the manure produced on it. I will take the farm of Bechelbronn as an example. This property consists of about 275 acres, being divided into 125 acres of arable land and 150 of meadow land. According to the ancient tradition this farm is placed under excellent conditions, for just as much manure is produced as the crops take away from it. But how much manure is

¹ As a general rule the prices of chemical products intended for manure increase twice a year, in autumn and in spring, when crops are sown. Not being able to follow all the fluctuations in the price of chemical products from day to day, we have adopted the prices current for the month of May, 1878 :—

	£	s.	d.	
Calcic superphosphate . . .	4	16	0	per ton
Potassic nitrate . . .	24	0	0	„
Sodic nitrate . . .	14	0	0	„
Ammonic sulphate . . .	20	0	0	„
Calcic sulphate . . .	0	16	0	„
Potassium chloride . . .	8	0	0	„

At this rate the equivalent of a ton of farmyard manure, according to the old formula, would be 11*s.* 2*d.* According to the new formulæ, however, in which the potassic nitrate is replaced by a mixture of potassic chloride and ammonic sulphate, the price does not exceed 10*s.* 11*d.* When potassic nitrate costs 32*l.* per ton, as it did in 1871, the advantage of the new formula is very evident. At the present time, according to the old formula, the equivalent of a ton of farmyard manure would amount to 12*s.* 5*d.*, whilst with the new it reaches only 10*s.* 9*d.* I attribute this mainly to the introduction of potassic chloride into the composition of chemical manures. This depression in price of potassic nitrate still continues.

produced, and how much does the land receive per acre? The manure produced amounts to 710 tons per annum, which, spread over the 125 acres of arable land, and 25 acres of meadow upland, gives a mean, let us say, of 4 tons 16 cwt. per acre per annum. But the annual application of 4 tons 16 cwt. per acre of manure is insufficient. To farm under such conditions is to farm without profit. You will judge of this by the crops which are obtained at Bechelbronn:—

	Per acre
Wheat . . .	20 bushels
Oats . . .	35 bushels
Beetroot . . .	10 tons 8 cwt.
Meadow grass . . .	1 ton 16 cwt.

At Bechelbronn, therefore, they grow but small crops, and at a small profit; in fact, if we calculate the interest on capital at only 3 per cent., the profit barely amounts to 132*l*.

It may also be remarked that if the farm at Bechelbronn were converted into a commercial establishment, out of the net profits of 132*l*. we should have also to deduct a manager's salary. Is this to be given as an example of that commercial prosperity which would enable French farmers to struggle against foreign importers? We will, however, change these conditions, and see what could be done for Bechelbronn by the aid of chemical manures.

If only 1*l*. 18*s*. 4*d*. per acre were expended, or 240*l*. in all, this is what would happen: The yield of each acre would jump from 20 to 33 bushels per acre, or 13 bushels increase—that is to say, an excess of value in the crops of 3*l*. 16*s*. 8*d*. for an outlay of 1*l*. 18*s*. 4*d*. per acre, without counting the value of the straw. Let us reduce, if you please, the profit by one-third, and place it at from 1*l*. 10*s*. to 1*l*. 12*s*. per acre, and there still remains the fact that by the expenditure of 240*l*. the profit can be raised from 132*l*. to 280*l*. and 320*l*. You will notice that I put everything down at a low figure. This ought not to surprise you now that the advantages of high cultivation are familiar to you. Again, at Bechelbronn, without changing anything in the mode of cultivation, but by the sole use of 1*l*. 18*s*. 4*d*. worth of chemical manure per acre, the profit might be trebled. This is a striking demonstration, it seems to me, of the truth of the principle, that in farming there is no profit without copious manuring; and seeing that it is impossible to produce sufficient manure for this high kind of culture, we must necessarily have recourse to a supplement in the form of chemical manure. This is a serious question, and it will not do to shut our eyes in its presence.

It may be said that this proposition may be disputed on account of the example I have chosen, and that there are farmers who set to work in a more advanced manner, those, for instance, who have added sugar refineries or distilleries to their farms, and for whom an importation of manure is not necessary; but even under these conditions the farmer who is reduced to his own resources cannot manure with sufficient generosity to yield him profitable crops.

M. Cavallier, whose farm has an adjunct in the form of a sugar refinery, can only produce 1,000 tons of manure per annum, which is hardly enough to supply 125 acres with 20 tons every two years. Under these circumstances M. Cavallier only obtains from 14 tons to 16 tons of beetroot per acre, whilst by using the normal manure one year he obtained 23 tons 16 cwt. per acre.

You will scarcely be surprised if in the presence of such results I tell you that M. Cavallier is going to permanently adopt the use of chemical manure. When farmers persist in using nothing but farmyard manure as their only fertilising agent, the quantity which is at their disposal is insufficient for growing heavy crops, the consequence being that their produce is but small, and their profits precarious.

In the past the following proposition was made into an axiom: for good farming we must have plenty of meadow, cattle and manure. But I assert that this proposition is an agricultural and economical heresy.

The farmer who uses nothing but farmyard manure exhausts his land. For whence comes the manure but from the soil? As a fact farmyard manure does not make up for the loss of the calcic phosphate, lime, potash and nitrogenous matter which it had to submit to through the carrying away of part, at any rate, of the crops grown on it. When meat is sold away from the farm less is lost than in the case of grain, but there always is a loss. I repeat then that this axiom, which has hitherto been made into the foundation and palladium of agricultural science, is nothing more than an expedient. It can only claim consideration in the very exceptional case of a meadow being watered by a river which returns to the soil the fertilising agents which have been taken out of it. I repeat, however, that such cases are so rare that they cannot form a law.

I have said that farming founded on the use of farmyard manure alone is, economically speaking, against common sense. Take the case, for instance, of a piece of somewhat poor land, yielding no more than from 9 to 11 bushels per acre; calculate how long it would take to make it produce

two and a half or three times that quantity, and you would shrink back before the sacrifices that you would have to make. With chemical manures the change is immediate, the progress sudden, and the profit immediate also. But if, as we may remark, besides the profit, we increase from the very first year the crop of straw, is it not evident that instead of growing meat in order to have corn, there is a manifest advantage in reversing the recognised order of things, and commencing to grow corn in order to gain the earliest advantage? in fact, we get corn first and manure afterwards. I repeat then that the soil cannot do otherwise than exhaust itself unless we bring in from outside a large amount of fertilising material. The solution of this question, imposed on us by the force of circumstances, seems to be that we must increase the fertility of the soil by means of chemical manures composed of substances existing in the mineral kingdom, which appear to us to have been specially reserved to repair the depredations of the past and of the present, and to guard us against the effects of such disasters for the future. It is, therefore, not correct to say that with farmyard manure and nothing but farmyard manure, we have everything required. It is, however, true to say that in order to obtain large crops there is only one method at our command, and that is to have recourse to chemical manures in preference to all others, because their composition has been rigorously defined, and is always identical, because they are the only ones in fact in regard to which fraud cannot be practised, and also because they are, according to my own opinion, the most economical.

Try to discover practically the real value of some of the wonderful qualities supposed to be possessed by the products of certain manure merchants, and you will find that you will have to pay a heavy profit. Now that the primary conditions of fertility have been ascertained, we need no longer take into consideration a tradition which belonged to a bygone age of agriculture. We now govern the requirements of farming instead of being governed by them. I can only repeat what I have already said on the occasion of a lecture delivered by me at the Sorbonne, entitled "The Agricultural Crisis and Science:" "Farmers are no longer under the necessity of providing their own manure, they will be providers of their own fertilising agents if they can make it pay in the end, but if they find it more profitable to have recourse to chemical manures there is nothing to prevent them; it is no longer a question of good farming, but one of cost price".

When we wish to introduce into a farm these new

methods of arriving at the maximum of production, a change has to be made of which it is necessary I should say something, seeing that it is destined to give to agriculture proper an important portion of those lands which were formerly devoted to forage, without, however, interfering with the resources which are devoted to this purpose. The change which it is advisable to make in this respect consists in substituting as far as possible the growing of lucern in place of grass. I may quote on this subject the testimony of two authorities who are equally important, that of M. Boussingault, who acknowledges that fields of lucern are more profitable than grass lands, and that of M. Schattenmann, who has made the substitution of which I speak with great advantage. Every one can see that at Bechelbronn if the necessary food for the cattle was provided for as well as the straw for their litter, 30 to 40 per cent. of the meadows on the farm which are now devoted to one or other of these purposes would be at liberty. This would produce a large increase of income, more especially if these vacant fields were devoted to the cultivation of profitable crops fertilised with strong doses of chemical manure. The importance of such a result is all the greater, seeing that it can be carried out immediately with a very small amount of capital.

In this lecture I have laid down the principle that chemical manures, of which I at first studied the exclusive use, may be associated with advantage with farmyard manure, and I have pointed out the spirit which ought to govern this new application. To complete these preliminary instructions, it only remains for me to resume the consideration of these questions in detail, and to point out the best formula for each special case. This complement to our preliminary inquiries is all the more necessary, as the production of farmyard manure is an absolute necessity as soon as ever there is a question of carrying on a farm on an important scale. This new subject will form the groundwork of our next lecture.

LECTURE VI.

COMBINATION OF MANURES (CONTINUED)—WASTE PORTION OF CROPS IMPORTANT AS FERTILISERS—CHEMICAL MANURES FROM A FINANCIAL POINT OF VIEW.

IN the cultivation of a farm of any considerable size it is indispensable to have recourse to animal labour; the handwork of labourers, which is characteristic of small holdings, is only possible as soon as we begin to operate on a somewhat important scale, when we grow certain crops which produce abundantly, such as the vine, the hop, tobacco, &c. I repeat then, that as soon as we enter on the domain of large farming properly so-called, the use of animal labour becomes a necessity from the force of circumstances under which manure is produced and must be profitably and regularly used.

I take up the question, then, from the point where I left it in our last lecture; and in order to complete the general ideas which I have laid before you on the use of farmyard manure in conjunction with chemical manures, it only remains for me to point out to you the practical rules to be observed in this case. Our first example will be a series of crops grown in rotation for five years as practised at Bechelbronn:—

1st year potatoes.	4th year wheat.
2nd „ wheat.	5th „ oats.
3rd „ clover.	

At the beginning of the period the soil received some 16 to 20 tons of farmyard manure. In 20 tons of farmyard manure the four ingredients of our normal manure are contained in the following proportions:—

Nitrogen	181 lbs. per acre
Potash	164 „
Phosphoric acid . .	87 „
Lime	352 „

It should be remembered that more than one-third of the nitrogen is lost to the soil on account of the decomposition which the manure must first undergo before it can exercise

its action. This fact explains the reason why we obtain such miserable results when only a small quantity of manure is used. To change this state of things, we must place the land under the proper conditions for high cultivation, by at least doubling the amount of the fertilising substances contained in the farmyard manure by means of chemical manures, and concentrate in the case of each particular plant that particular substance of the four contained in our normal manure which is especially favourable to its growth. In the case of the series we are speaking of, I propose to make the following subdivision of our supplementary substances:—

SERIES OF CROPS GROWN FOR FIVE YEARS.

POTATOES, WHEAT, CLOVER, WHEAT, OATS.

First Year.

POTATOES.

	Quantities Tons	Per acre Cost		
		£	s.	d.
Farmyard manure	20			
Normal manure, ¹ No. 6, 440 lbs.		1	8	5

Second Year.

WHEAT.

	lbs.			
Ammonic sulphate	176	1	12	0

Third Year.

CLOVER.

Incomplete manure, ² No. 6	880	1	10	10
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Fourth Year.

WHEAT.

Ammonic sulphate	176	1	12	0
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Fifth Year.

OATS.

Ammonic sulphate	264	2	8	0
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Cost for five years	£8	11	3
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The cost for the five years per acre was 8*l.* 11*s.* 3*d.* at the annual rate of about 1*l.* 14*s.* 3*d.*

With farmyard manure only the potato gives 4 tons 16 cwt.

¹ For composition, see p. 54.

² For composition, see p. 51.

per acre; the wheat, 20 bushels; the oats, 33 bushels per acre, and the clover 2 tons of dry forage per acre. With the chemical manure added, the yield of potatoes gives 8 tons; the wheat 33 bushels; the oats, 49 to 53 bushels, and the clover at least 3 tons 4 cwt. of dry forage.

If we replace potatoes by beetroots we must substitute the following manure for the first year:—

	Per acre	
	Quantities lbs.	Cost £ s. d.
Normal manure, ¹ No. 2 . . .	528	2 4 8

The other manures remain the same, but the expense of the five years is increased to 9*l.* 7*s.* 6*d.* per acre, which brings up the annual expense to about 1*l.* 17*s.* 6*d.* per annum. With the farmyard manure, however, the crop is only about 10 tons 8 cwt. per acre, while with the additional manure they reach at least to 16 or 18 tons.

In districts favourable to the growth of the colza and the beetroot, such as the department of the Somme, it is found to be very profitable to precede the beetroot with a crop of colza, on which is to be expended all the manure possible. The ground is thus better prepared for the subsequent cultivation of cereals, and the farmyard manure having become perfectly decomposed, contributes more efficiently to the growth of the beetroots.

If we modify the preceding rotation in this way, the following is the best method of dividing the manure:—

SERIES OF CROPS GROWN FOR FIVE YEARS.

COLZA, BEETROOT, WHEAT, CLOVER AND WHEAT.

First Year.

COLZA.

	Per Quantities	acre Cost	
		£	s. d.
Farmyard manure	20 tons		<i>nil</i>
Ammonic sulphate	264 lbs.	2	8 0

Second Year.

BEETROOT.

Ashes from burnt colza	—		
Haulm and pods	—		
Normal manure, ² No. 2, 528 lbs.		2	4 8

Third Year.

WHEAT.

	lbs.		
Ammonic sulphate	176	1	12 0

¹ For composition, see p. 52.

² For composition, see p. 52.

Fourth Year.

CLOVER.

	Quantities lbs.	Per acre Cost		
		£	s.	d.
Incomplete manure, ¹ No. 6	880	1	10	10

Fifth Year.

WHEAT.

Ammonic sulphate	176	1	12	0
		<hr/> £9 7 6		

The cost for the five years is 9*l.* 7*s.* 6*d.* per acre, or nearly 2*l.* per annum. We can always replace the second crop of wheat, which succeeds the clover, by a crop of oats. By doing this we save the ammonic sulphate recommended for the fifth year, reducing the five years' cost to 7*l.* 15*s.* 6*d.* per acre, the annual expense being reduced to 1*l.* 11*s.*

As a last example I will give a specimen of a six years' series in which the chemical agents are employed alone the first year, and are only used in combination with the farm-yard manure from the second year onwards. The following is the composition of the series:—

1st year linseed.	4th year colza.
2nd „ beetroot.	5th „ wheat.
3rd „ wheat.	6th „ oats, rye or barley.

I have said that the first year we ought not to employ anything but chemical manures, their superiority for flax-growing being beyond all doubt. Linseed may be sown from this point of view between wheat, which requires, as you know, a manure rich in nitrogenous matter, while leguminous plants require the mineral portions of the mixture. It succeeds better, therefore, with chemical manures, because the nitrogenous portion may be reduced without affecting their mineral constituents. I have already quoted the results obtained by M. Chavée, whose crop was sold all standing at the rate of 14*l.* 14*s.* per acre.

SERIES OF CROPS GROWN FOR SIX YEARS.

LINSEED, BEETROOTS, WHEAT, COLZA, WHEAT AND OATS, RYE AND BARLEY.

First Year.

LINSEED.

	Quantities lbs.	Per acre Cost		
		£	s.	d.
Incomplete manure, ² No. 6	880	1	10	10

¹ For composition, see p. 51.

² For composition, see p. 51.

Second Year.

BEETROOTS.

	Per acre Quantities	Cost £ s. d.
Farmyard manure laid down in autumn	20 tons	nil
Normal manure, ¹ No. 2, laid down in spring	lbs. 528	2 8 10

Third Year.

WHEAT.

Ammonic sulphate	176	2 3 2
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Fourth Year.

COLZA.

Normal manure, ² No. 1	1,144	4 17 7
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Fifth Year.

WHEAT.

Ashes of haulms and pods of colza ploughed in		
Ammonic sulphate	264	2 8 0

Sixth Year.

OATS, RYE OR BARLEY.

Ammonic sulphate	176	1 12 0
------------------	-----	--------

Per acre for six years	£15 0 5
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This account is a somewhat heavy one, but regard must be had to the nature and value of the products. Putting things at their lowest, I should say that the mean value of the whole of the crops for the six years would be 16*l.* to 17*l.* 12*s.* per acre.

I might multiply examples and quote instances of other series of crops, but as they would all require the application of the rules and principles which we have already laid down, I prefer to recall to your remembrance those rules and principles, by which means you will be enabled to substitute your own initiative for mine, and compare for yourselves the formula and proportions of the manure.

I have remarked several times, and I repeat it once more, that farmyard manure owes its value to the nitrogen, calcic phosphate, potash and lime which it contains. For if we experiment side by side with farmyard manure, and with a mixture of these four bodies of equal richness, the crop obtained with the chemical will always be superior to that obtained with the farmyard manure.

¹ For composition, see p. 52.

² For composition, see p. 50.

I have told you besides that one of these substances is always subordinate or predominant as regards the three others according to the kind of plants which we are growing. Thus nitrogen, which is the dominant constituent in the case of wheat, descends to the rank of a subordinate agent in the case of leguminous plants. But notwithstanding this change it is a noteworthy fact, on which I cannot too strongly insist, that this predominancy only manifests itself on the express condition that the soil is provided to a certain extent with the other three constituents of a normal manure. Nitrogenous matter is the dominant material in the case of wheat and colza; in a soil of pure sand, however, nitrogenous matter produces scarcely any effect; but add the other mineral constituents to the sand, and the nitrogenous material gives a rapidity of growth which is astonishing, and within a certain limit the crop corresponds to the amount of nitrogen present.

This being so, you will understand the part played by farmyard manure when used with that prepared artificially. Owing to its nature and its bulk it necessarily acts very slowly, its virtue being subordinated to the previous decomposition of the carbo-hydrates, which, with water, form 95 per cent. of the whole. Under these conditions farmyard manure becomes the equivalent of a large amount of acquired riches. With farmyard manure alone great crops are impossible, because the entire amount of substances capable of being assimilated is never sufficient. But add yearly to the manure the ingredients required by each crop, and the crop and the consequent profit will soon attain their highest limit. If I now recall to your memory the fact that nitrogenous matter predominates in wheat, colza and beetroot, potash in leguminous plants, calcic phosphate in turnips; that the mineral matter so often mentioned gives without nitrogen the largest lucern crops, that the same mineral matter with the addition of a little nitrogen is best for potatoes and linseed; you will not only understand the rules which have guided me in the directions I have already given you, but you will also be able with their aid to combine series of crops appropriate to the circumstances under which you are placed.

This, however, is not sufficient. In order that the solution of the great problem of agricultural production may be thoroughly complete, it is not only necessary to be acquainted with the agents which are the source of fertility, but we must also be certain that we are not impoverishing the soil by taking away from it more than we put into it. The question then is:—

Can we, with chemical manures, cultivate the same soil with uniform success? My answer is absolute. Yes, we can; but always on two conditions.

(1) Return to the soil by the aid of manure more calcic phosphate, potash and lime than the crops have taken out of it.

(2) Restore to the soil about 50 per cent. of the nitrogen of the crops. I say *about* 50 per cent. because there are certain plants which require less, while others, leguminous plants for instance, seem to be able to do without any nitrogen being returned to the soil. We have already stated that part of the nitrogen required by plants is derived from the air, while some plants seem to draw it more particularly from the soil.

With respect to the calcic phosphate, potash and lime, the quantity restored must be in excess of that which has been lost, because it is exclusively from the soil that plants draw them, and we must not only give compensation for the losses brought about by each harvest, but also for those which are due to the solvent action of rain. Let us examine if the formulæ for manures which I have given satisfy the two conditions which I have just pointed out. I stated in the last lecture that wheat could be grown for an indefinite period on the same land, provided the land is manured as follows:—

The Culture of Wheat.

FOR AUTUMN.

Normal manure, ¹ No. 1A, 528 lbs.	£	s.	d.
	2	5	11

FOR SPRING.

Nothing, or ammonic sulphate, 44, 88, or 132 lbs.	1	4	0
	<hr/>		
	£3	9	11

By means of this quantity of manure we may easily obtain 34 bushels of wheat, and 2 tons of straw per acre. If we strike a balance between what the manure has given to the soil and what the crop has taken away from it, we shall always find the result in favour of the soil:—

¹ For composition, see p. 50.

PER ACRE.

	Manure	Crop	Loss to soil	Gain to soil
	lbs.	lbs.		lbs.
Nitrogen, 61 lbs. . . .	121	104	<i>nil</i>	17
Phosphoric acid . . .	26	22	„	4
Potash	44	25	„	19
Lime	35	2	„	33

In the presence of these figures we may safely say that the use of chemical manures has nothing to fear in the future. My experiments in calcined sand, confirmed by others in the open field at Vincennes, twenty-one years ago, seem to me to place this conclusion beyond dispute. In the preceding example I assumed that the whole of the crops, both straw and grain, were lost to the farm; I also assumed that the land was cultivated by hand labour. By this double assumption the demonstration was carried to the extreme. It is to be regretted that many of the small farmers in France are almost entirely unprovided with manure, and thus, by the extent of the interests represented, they affect the public welfare to a very serious extent.

I now pass to the system of growing alternate crops of colza and wheat; taking it for granted that everything is sold, wheat, straw, pods, haulm and all. The distribution of manure is supposed to last for two years.¹

Nitrogen, 137 lbs. per acre, equivalent in the crop to .	274 lbs. per acre
Phosphoric acid	53 „
Potash	83 „
Lime	137 „

¹ The succession of manures was as follows :—

First Year.

COLZA.

		Per acre		
		Quantities	Cost	
		lbs.	£	s. d.
Calcic superphosphate . . .	352	0	15	4
Potassic nitrate	176	1	18	5
Ammonic sulphate	220	1	16	8
Calcic sulphate	308	0	2	3
		<hr/>		
		4	12	8

Second Year.

WHEAT.

Ammonic sulphate	352	3	4	0
		<hr/>		
		£7	16	8

or 3*l.* 18*s.* 4*d.* per annum.

The two crops¹ of colza and wheat contained :—

Nitrogen	259 lbs. per acre
Phosphoric acid	59 „
Potash	118 „
Lime	123 „

If we now strike a balance we shall find that the soil has decidedly lost in two places :—

PER ACRE.

	Manure	Crops	Loss for the soil	Gain for the soil
	lbs.	lbs.	lbs.	lbs.
Nitrogen	274	260	—	14
Phosphoric acid	53	59	6	—
Potash	83	118	35	—
Lime	137	123	—	14

These manures seem not to be rich enough, and their prolonged use would appear at last to damage the fertility of the soil, yet in reality this is not the case. To simplify the discussion I admitted that the preceding experiment was performed by hand labour, and that everything was sold, both straw and grain. But the haulm and empty pods of the colza have no market, and could never under any circumstance command a sale. If, however, they are burnt in the fields, and their ashes are sown broadcast, the soil will receive sufficient potash and phosphoric acid to compensate it for the amount it has lost. In fact this restitution is greater than necessary, and instead of being deficient in potash and phosphoric acid, the soil has now an excess of both.

¹ The following are the details of the crops :—

		Nitrogen	Phosphoric acid	Potash	Lime
		Tons Cwt.	lbs.	lbs.	lbs.
One crop of colza	{ Haulm	2 1	47½	7	43½
	{ Pods	0 18	22½	4	64½
	{ Seeds	0 19	86	26½	14½
One crop of wheat.	{ Straw	1 15	31½	4½	12
	{ Chaff	0 5½	6	1	1
	{ Grain	1 1½	66	16	11½
			259	59	118
					123½

To demonstrate how those waste portions of crops which have no commercial value whatever may acquire great importance as a source of fertility, I will once more give the table containing the composition of the two crops of colza, and again strike our balance on the supposition that the haulm and the pods of the colza have been burnt on the soil, and that only the seed has left the farm.

Composition of One Crop of Colza.

	Crop	Nitrogen	Phosphoric acid	Potash	Lime
	Tons Cwt.	lbs.	lbs.	lbs.	lbs.
Haulm . . .	2 14	47 $\frac{1}{2}$	7	14 $\frac{1}{2}$	43 $\frac{1}{2}$
Pods . . .	0 18	22 $\frac{1}{2}$	4	64 $\frac{1}{2}$	63
Seeds . . .	0 19	86	26 $\frac{1}{2}$	14 $\frac{1}{2}$	6 $\frac{1}{2}$

Balance rectified by the Burning of the Haulm and Pods of the Colza.

	Manure	Taken by the crops	Loss for the soil	Gain for the soil
	lbs.	lbs.		lbs.
Nitrogen	274	260	—	14
Phosphoric acid . . .	53	48	—	5
Potash	83	39	—	44
Lime	137	16	—	120

This new example shows the necessity, when we make our calculations relative to the rotation of crops, of remembering that the *whole* of the produce carried away from the soil is not lost to it. The waste which is thrown on the dunghheap returns ultimately to the soil, and cannot be included in this category.

A third case may possibly present itself, leaving the intervention of animals out of the question. It is that in which the small grower, who, being a long distance from any railway town, can no more sell his straw than if it were colza haulm. What is he to do? He has a choice of two ways out of the difficulty: he may either make his straw into a bonfire as he did with his colza haulm, or he may transform it into a manure heap by letting it lie until it rots. If wheat straw and colza haulm be piled in a heap in alternate layers and sprinkled with water into which a few hundredweights of rape cake have been thrown, the mixture will act like urine

on a dungheap, and speedily bring about the entire decomposition of the mass. At the end of three or four days the mass will become heated in the centre, giving out a temperature of 50° or 60° C. (122° to 140° F.), and in from fifteen to twenty days the ligneous fibre will have become quite disintegrated and have assumed a half-pasty condition, resembling that of farmyard manure.

Which of the two methods is the best? By the putrefactive process we avoid an important loss of nitrogen; there is, however, the expense of labour to be considered on account of the cartage of the straw from one place to another, the preparation of the manure heap and its application to the land. By burning we avoid these expenses, but we lose all our nitrogen, and have to supply its place by purchasing ammoniac sulphate or sodic nitrate.

For my own part I have no choice between the two methods; in practice they are about equally valuable, and it is the comparative expense of the two processes which must determine the farmer's choice.¹ If we consider cases of a more general nature, in which the field work is performed by animals, and in which the production of manure is a matter of necessity, the problem remains the same, and the rules which have already guided us continue to be applicable.

In fact, what is the nature of manure? It consists of vegetable products modified by digestion. The manure heap, like the refuse of crops, depends for its value on the nitrogen, and on the potassic salts and calcic phosphates which it contains.

I will not here give in detail the balance sheet of the series of rotations in which farmyard manure is combined with chemical manure, because the importance of the real losses to which the soil is liable depends upon how completely the crops grown on it are carried off to other localities, and on the keeping of cattle; but in order to give you the means of doing this—for being able to keep accounts intelligently and make calculations is a necessity on every well-ordered farm—I have arranged in a tabular form as an appendix the average composition of manures and of all the crops included in the series I have already laid before you.

Let us now consider the question of chemical manures from a financial point of view, taking for our first example a case in which chemical manures alone are employed.

¹The introduction of decaying vegetable matter or humus into the soil is very beneficial since it improves the texture and water-holding capacity of the latter: on this account it should not be burnt.

Nothing is so variable as a farming account. Everything affects it: the locality, the relative abundance or scarcity of labour, and the system of farming pursued. It is impossible to present such an account without meeting all kinds of objections drawn from each person's own experience. To avoid this inconvenience I shall confine myself to placing opposite each other the cost of the manure and the value of the crop, leaving every one to draw his own conclusions according to the circumstances in which he is placed. The yield being 34 bushels per acre and 2 tons of straw, if we fix the price of grain at 5s. 10d. per bushel and that of the straw at 1l. 8s. per ton, the crops will be worth per acre:—

	£	s.	d.
	12	14	4
Annual cost of manure . . .	3	10	5
Balance, being profit . . .	£9	3	11

It will perhaps be said that in this valuation I have not included the cost of carriage of the manure. The observation is a just one, for we ought also to add the sum of 1l. 4s. for this item, when there will remain 8l. for ground rent, taxes, general expenses and interest on capital.

I shall now examine a second hypothesis which specially applies to farming, both on a large and a medium scale; an establishment, for instance, conducted in the old-fashioned way, the profits of which are but small, the owners of which, however, have a desire to change their system for something more modern whereby they may increase their crops, but at the smallest outlay possible. In order to give greater precision to what follows, I will again take Bechelbronn as an example.

At this farm they only use farmyard manure, and out of 275 acres which compose the farm 150 acres are meadow land and 125 arable. The gross produce obtained during the year is valued at 814l. 8s., the working capital being 1,400l.

Cultivation with Farmyard Manure only.¹

	Acres in culti- vation	Yield		Produce	
		Per acre	Total	Per acre	Total
Potatoes .	17½	4 tons 18 cwt.	85 tons 15 cwt.	£ 8 16 0	£ 154 0 0
Beetroot .	7½	10 „ 10 „	78 „ 15 „	6 14 10	50 11 3
Wheat (grain)	50	20 bushels	1,000 bushels	5 15 6	288 16 0
„ (straw)		1 ton 6 cwt.	65 tons	1 6 0	64 17 7
Clover .	25	2 „ 7 „	58 „ 15 cwt.	5 2 0	127 12 0
Oats (grain) .	25	34 bushels	850 bushels	4 17 4	120 0 0
„ (straw) .		15 cwt.	18 tons 15 cwt.	0 11 10	14 19 2
					820 16 0

With an increased outlay of 1*l.* 18*s.* 4*d.* per acre for manure this sum of 820*l.* 16*s.* might be increased to 1,254*l.* 1*s.*, leaving a profit of 433*l.* 5*s.* instead of 132*l.*

Cultivation with a Mixture of Farmyard Manure and Chemical Manure.

	Acres in culti- vation	Yield		Produce	
		Per acre	Total	Per acre	Total
Potatoes .	17	8 tons	140 tons	£ 14 8 8	£ 252 0 0
Beetroot .	7½	16 „	120 „	10 4 10	76 16 0
Wheat (grain)	50	33 bushels	1,650 bush.	9 7 2	468 0 0
„ (straw)		1 ton 16 cwt.	90 tons	1 16 0	90 0 0
Clover .	25	3 „ 4 „	80 „	7 0 0	176 0 0
Oats (grain) .	25	50 bushels	1,250 bush.	6 16 10	171 5 0
„ (straw) .		1 ton	25 tons	0 16 0	20 0 0
Total production					1,254 1 0

¹ These are the prices fixed in the account of M. Boussingault:—

Potatoes . . .	£1 16 0	per ton
Beetroot . . .	0 12 10	„
Clover . . .	2 4 0	„
Wheat straw . .	1 0 0	„
Oat straw . . .	0 16 0	„
Wheat . . .	0 5 10	per bushel
Oats . . .	0 2 10	„

	£	s.	d.
Total produce of cultivation with mixture of farmyard manure and chemical manure	1,254	1	0
Total produce with farmyard manure only	820	16	0
Difference in favour of the first system	£433	5	0

A sum of 433*l.* 5*s.* as an excess of income against an outlay of 240*l.*, the profit being 90 per cent. The working capital already being 1,400*l.*, it would be only necessary to make it 1,640*l.* to triple the profit. I need not add that in both cases the selling prices are the same. I accept without change the prices which M. Boussingault has taken as his basis of valuation.¹

Is this result the greatest that can be obtained? Far from it. I have estimated the crops at 20 per cent. below their actual value. The following results were obtained by M. Lavaux at the farm of Choisy-le-Temple (Seine-et-Marne):—

	Yield per acre
1865, Wheat	44 bushels
1866, Colza	36 „
1867, Spring wheat . .	37 „
1867, Beetroot	24 tons

The excess of profit which may be realised on the 125 acres of arable land on the Bechelbronn estate is not the only advantage to be gained from the use of chemical manures.

To obtain sufficient manure for the 275 acres comprising the estate, 60 are given up to meadow land, the yield of which hardly exceeds from 1 ton 12 cwts. to 2 tons of hay per acre.

By means of a suitable formula for manure this yield might be increased to 3 tons 4 cwts.; this would at once set free, without any diminution of produce, some 40 or 50 acres, which would then be available for more profitable crops.

You know, of course, the result which would be obtained by turning the meadows into lucern fields.

The use of chemical manures in the present case would be followed by two equally advantageous results; the whole produce would be increased, and the ground used for cattle feeding might be reduced in size without diminishing the number of the animals, or their number might be increased by 30 per cent. by keeping the land in its original state.

As long as agricultural science could give us no positive

¹ I am told that Bechelbronn has been under two systems of working. The whole of the above refers to the time before the change, when M. Boussingault was director.

information about the true agents of fertility, the production of manures and the growth of cereals were a most important item. Farmers, therefore, could not make their meadow lands less than half the size of their whole farm without running the risk of exhausting the soil and involving themselves in inevitable ruin.

Under this system it was the duty of the meadow to obtain its nitrogen from the air, while cereals were expected to find it in the soil. Cattle were looked upon as the providers of manure, and the hay of the meadow and the straw of the wheat-field were devoted to their use when they could not be sold.

By the use of chemical manures the agricultural problem has become simplified, and is susceptible of a much more independent solution. There was no question about the matter being an absolute rule. Form meadows and breed cattle in order to have cereals is a dictum which nowadays loses the character of an axiom which it once possessed. I will add that at the present day this axiom would be an agricultural solecism and an economic heresy, seeing that with farmyard manure only crops are always small, corn yielding scarcely at the rate of 5s. 8d. per bushel, a figure which cannot be a paying one. I say, then, that this axiom need no longer be imposed upon farmers as a necessity. Besides, you are well aware that the true agents of fertility being now known, farmers need only increase their stock of manure when they find it profitable to do so; where this is not the case, the solution of the question is perfectly simple: they have only to use chemical manures. It is then no longer an agricultural question, but one of profit and loss.

The farmer is now no longer obliged to produce his own manure, but to manure more generously than in the old days, no matter what material he may use, whether it be farmyard manure or chemical manure, either separately or together. In every case, however, he must remember that he has two rules to follow:—

(1) Restore to the soil more phosphates, more potash, and more lime than the crops have taken out.

(2) Give back 50 per cent. of the abstracted nitrogen.

You now see in what way our modern mode of procedure differs from the ancient. Formerly you were under the sway of a law by which you were dominated; you were obliged to make the meadow, and the ox grazing in it, the means of maintaining the equilibrium between the coming in and going out of the manure.

In the past nitrogenous matter had its sole origin in the

meadow. Potash, lime and the phosphates come from the meadow and the cattle lairs, while improvements were tried in the dark, and without rhyme or reason.

In former times, when the meadow was the sole source of manure, crops were necessarily low because the sources of manure were insufficient. For instance, an acre rarely produced more than 20 to 22 bushels of wheat, 4 to 4 tons 16 cwt. of potatoes, and 12 tons of beetroot. Under such conditions agriculture became next to impossible.

Nowadays there is but one thing that hampers us, and that is the necessity for keeping animals for preparing the soil and for traction purposes. Beyond this we possess entire liberty of action, a liberty without limit, and we only grow meat and manure because we find it to our advantage. Even when we choose to keep cattle we can do so on a much smaller space than formerly, or we can produce a greater quantity of meat on a given spot because we can increase our meadow crops just as we do all others.

We are obliged to return to the soil more than we have taken out, but this law does not impose on us the necessity of making more manure than we require for our own interests. We can satisfy our needs with foreign manures, the nature and quality of which may be determined at any time by fixed rules.

Whoever tries to understand the problems that agitate the present age will easily see the connection which must exist between the higher interests of our country and the question we are now trying to notice. At a period when the means of communication had not reached the development which they have now acquired, the home markets of the country afforded certain and easy outlets for agricultural produce; but in the present day what with free trade and the facility of transport which we possess, farmers are called upon even in their own markets to compete with the productions of the entire world. In order that the struggle should be feasible and successful it is absolutely necessary that crops should be made to yield to their utmost limit. With old-fashioned methods this is impossible except we change the whole of our agricultural system; this could not be done suddenly, and would besides want such a formidable capital that it would be absurd to dream of it.

With chemical manures the question is different, and reduces itself to this simple proportion. Add 1*l.* 18*s.* per acre to the amount you already expend on manure, or spend from 2*l.* 17*s.* 6*d.* to 3*l.* 4*s.* if you have no manure, and the result will soon be shown by increased crops, the value of which

will be double the excess of the outlay. There is no objection which can be raised to this proposition. It is a fact. My most earnest wish is that the methods which it has been the function of the experimental farm at Vincennes to make known may receive still more general application every day. I ask that they may be rigidly controlled by the experience of practical men, and if the progress which I expect to see made through this control causes my own efforts to be in time forgotten, I shall nevertheless easily console myself, persuaded, as I shall be, that my country will receive from the application of these new methods an incalculable increase of wealth and prosperity.

PART II.
ON CHEMICAL MANURES.

PRACTICE EXTENDED BY THEORY.

LECTURE VII.

PAST AND PRESENT SYSTEMS OF AGRICULTURE.

IN preceding lectures we have considered the conditions and laws which favour, determine and regulate plant life. I now propose to consider the subject from a more practical point of view. I will, however, first refer to the nature and extent of the progress which was made in agriculture in past times. I also wish to show how our present efforts are the continuation and the crowning, so to speak, of the past. If we go back as far as possible in the history of the human race, we find that wherever man lived he sought for the means of subsistence in two parallel methods of cultivation; and, guided by a sort of infallible instinct, he chose for the purpose spots covered with alluvial soil, the slopes of hills, deep valleys intersected with water-courses, or the banks of great rivers. Thus the art of agriculture in past times was summed up in the one word—irrigation¹—the result of observing the good effects produced by natural inundations. Egypt is at the present day a striking example of this system, which is imposing both on account of its antiquity and the important results produced by it.

But this mode of culture is not the only one to which infant communities have had recourse. On the vast plateaus of Central Asia, and in many parts of Africa, tribes live in a nomadic state. What is the system of agriculture which is practised under these conditions? A limited culture of barley and wheat with long intervals, during which the land is allowed to lie fallow, and the breeding of numerous flocks and herds which roam at will over immense tracts of land. Now what is the explanation of these two primitive methods of culture viewed by the light of contemporary science, but the tacit avowal that the soil must receive back a part of that which has been taken from it.

The agriculturist of past days, like the Asiatic nomad, knew nothing of the reason for this; but experience told him that an act of restitution was necessary, as without it

¹ Only, however, where the rainfall is scanty and intermittent.

successive crops could not be grown. In one place it was by irrigation that this act was accomplished; in another, by the grazing of cattle, or by allowing the land to lie fallow.

By irrigation there was an importation of foreign matter, and in the feeding of cattle and fallow land the restitution was from the soil itself, and was the result of the better utilisation of existing resources. But the chief reason which dominates all the rest is the implied acknowledgment that the soil is provided with only a limited proportion of the substances required by vegetation, and that to insure and preserve its fertility these substances must be supplied to it.

Owing to the increase of population these two systems were in time found to be insufficient, and it became necessary to cultivate districts where irrigation was not possible, the system of pasture being no longer practicable on account of the great space it required.

It was then that one of the greatest improvements from an agricultural point of view, that history has handed down to us, was effected. The triennial system, which consists in the combination of the two preceding systems, was instituted. This consists in dividing the land into two nearly equal parts: the first being reserved for meadow land which was still fertilised by inundation, while the second was devoted to the production of cereal crops, but on the condition that the land was allowed to lie fallow for one year out of every two or three. The triennial system is then only the union of the two primitive methods, the pasture system and inundation, which cannot be applied separately except under special conditions of place and soil. How is the necessary restitution effected under the new system? By the same means. The meadow land receives by irrigation, and from the atmosphere, the equivalent of what it has lost; and in the portion set apart for cereals the restitution is accomplished by farm-yard manure, which has its origin in the hay of the meadow and the straw of the cereals. From this combination has sprung the celebrated formula, *meadow land, cattle, cereals*—a fruitful one certainly, but absolute and despotic, and antagonistic to the liberty of the individual.

It has been proved by universal experience that under the triennial system the average yield of cereals is about—

832½ lbs. of grain per acre—say 15½ bushels—and
1,628 lbs. of straw

2,460½ lbs. for the entire crop per acre per annum

or, to put it in round numbers, 2,500 lbs. per acre per annum.

If, on the other hand, we wish to know the quantity of farmyard manure required for the production of a similar crop, experience tells us that 5,860 lbs. per acre per annum will ensure an annual yield of over 2,500 lbs. of grain and straw.

If the two calculations which I have just quoted were absolutely exact everything would be explained, for the crop would be less than the manure used, and the earth would receive more than it had lost. But it is not so unfortunately. In the 5,860 lbs. of manure there are 4,646 lbs. of moisture, which it is absolutely necessary to allow for in order to have a correct result, as the following figures will show:—

Harvest	.	.	.	.	2,460 lbs.
Manure	.	.	.	.	1,214 „
					1,246 „
Surplus of harvest	.	.	.	.	1,246 „

Thus, for instance, with 1 ton of farmyard manure 2 tons of grain and straw are obtained.¹

¹ Boussingault, *Economie Rurale*, vol. ii., page 187:—

Triennial Rotation.

YIELD PER ACRE.

Year	Nature of Crops	Not dried	Dried	Containing				
				Carbon	Hydrogen	Oxygen	Nitrogen	Mineral matter
		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1st.	Fallow	—	—	—	—	—	—	—
2nd and 3rd	Farm-yard manure	—	—	—	—	—	—	—
	Wheat	2,920	2,495	1,150	145	1,083	57	60
	Straw	6,600	4,884	2,363 $\frac{3}{4}$	258 $\frac{3}{4}$	1,900	19 $\frac{1}{4}$	342
Total for 3 years		9,520	7,379	3,513 $\frac{3}{4}$	403	2,983	76 $\frac{1}{2}$	402
Farmyard manure		17,600	3,643	1,304 $\frac{1}{2}$	153	940	73	1,173
Surplus in favour of the crop		—	3,736	2,209 $\frac{3}{4}$	250	2,043	3 $\frac{1}{2}$	—
Surplus in favour of farmyard manure		—	—	—	—	—	—	771

The harvest for three years outweighs the manure by 4,506 lbs. in the organic elements, whilst the manure, on the contrary, prevails over the harvest by 771 lbs. in the inorganic elements.

It is not without a motive that I am leading you to this conclusion. It is not I who speak to you, but the experience of hundreds of years which has everywhere constantly proved the truth of this assertion—that a given quantity of manure will always produce double its weight of grain and straw, whether we use 1, 10, or 100 tons, or, in other words, that twice as much is obtained from the soil as we have given to it.

But agriculture in the present day is striving to steer clear of the triennial system. Towards the end of the last century a great improvement took place. Experience shows that it was no longer necessary to allow fields to lie fallow, and that by alternating wheat with trefoil, and beginning the rotation with a crop of potatoes, a yield of superior wheat would be obtained, and the amount of the crops would be greatly increased; also, that with these new combinations of culture the average crops were as heavy as under the triennial system.

But how is restitution effected under these new conditions? Exactly as in triennial rotation. The fields of potatoes and wheat are manured, whilst the meadows are fertilised by irrigation only. This system is, however, far more productive than the former, not only on account of the fact that the soil never remains inactive, but also because one and a half, if not two, of the four crops, trefoil and potatoes, are consumed on the farm. The following is the order in which the crops succeed each other:—

1st year, potatoes	|	3rd year, clover
2nd „, wheat	|	4th „, wheat

The land is not at rest an instant, and no longer lies fallow, and yet the general average of the crops is much larger. With cereals the grain crop increases from $14\frac{1}{2}$ to 24 bushels, and the straw from 1,628 to 2,219 lbs., which brings the total yield of dry crop up to 4,400 lbs. per annum, instead of 2,640 lbs. as obtained under the three years' system. This, then, is a great step in advance of the triennial method.

The advantage of being able to grow increased crops is, however, not the only one we have to mention. Another, quite as important, is the production of manure.

Under the triennial system the quantity of manure used is 5,860 lbs. per acre per annum, represented by 1,214 lbs. of dry matter. In alternate rotation, on the contrary, the crops increase in four years to 38,720 lbs., making the annual quota 9,680 lbs., which is equal to 2,006 lbs. of dry matter. If, however, the rotation system is decidedly superior to the

triennial, there is one point on which their testimony is unanimous. Here, again, with 1 ton of manure 2 tons of grain and straw are obtained. The system of alternate rotation leads us to the same conclusion, for with 2,000 lbs. of manure per acre per annum, we in reality get 5,000 lbs. of grain and straw.

It will thus be seen that by following the triennial system the crops are maintained indefinitely, at the same time level, whilst a like consequence results from the strict observance of the rules prescribed by the system of alternate rotation; whence the invariable conclusion that with 1 ton of manure you have 2 tons of grain and straw, or, in other words, that twice as much is gathered in as there has been manure used.

The conclusion to be drawn from the fact is, that it is a mistake to imagine that it is necessary to give back to the soil, weight for weight, pound for pound, and atom for atom, that which has been taken from it, for even when farmyard manure is used only a partial restitution is necessary.

But although this is the case, and the original fertility of the soil is nevertheless maintained, it is evident that some unseen source exists from whence vegetation draws the surplus. Normal manure possesses only a certain value. What, then, is this foreign source? It is to discover this, to ascertain under what form it presents itself, what is the nature of the agents it supplies to vegetation, and what is the amount of its importance, that we must now devote our efforts. Instead, therefore, of confining ourselves to a general comparison between manure and crops, we intend to analyse them both, and then to strike an exact balance between their respective elements.

In making this analysis we cannot fail to be struck with the fact that whatever may be the plant we are investigating we shall always find in the constitution of that plant about fourteen elements. (See p. 4, Part I.)

Let us now apply the principles I have laid down to the examination of the merits of the system of alternate rotation which I have just touched upon. On investigation we find that for the four years over which the rotation extends, the farmyard manure used amounts to 8,015 lbs. of dry matter, and the sum total of dry crops to 17,600 lbs. per acre, the elements contained in the manure and the crops being distributed as follows:—

Farmyard manure, 8,015 lbs.

	lbs.
Carbon	2,870
Hydrogen	336
Oxygen	2,068
Nitrogen	160
Mineral elements . .	2,581
Total equal to . .	8,015

Harvest, 17,596½ lbs.

	lbs.
Carbon	8,185
Hydrogen	951½
Oxygen	7,126½
Nitrogen	267
Mineral elements . .	1,066¼
Total equal to . .	17,596½

The signification of this analytical balance is singularly instructive.

Between the constituents of farmyard manure and those of the crop there is an important difference. Taking the inorganic elements for instance, we find that they are present in greater abundance in the manure than in the crop, whilst with the organic elements the reverse is found to be the case. But if things happen thus when a high system of cultivation is pursued, what takes place in the case of meadow land where no manure is used and everything is due to irrigation? We find that the yield is just as large as from land subjected

¹ Boussingault, *Economie Rurale*, vol. ii., page 189 :—

Alternate Rotation of Four Years.

YIELD PER ACRE.

Year	Nature of Crops	Not dried	Dried	Containing				
				Carbon	Hydrogen	Oxygen	Nitrogen	Mineral elements
		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1st . {	Potatoes	8,800	2,121	933	123½	947½	31½	85½
	Beetroot	1,960	2,147½	918¾	125	932	36	135½
2nd and 4th. {	Wheat .	3,198	2,733½	1,260	158½	1,186½	62½	66
	Straw .	7,040	5,033½	2,436¾	266¾	1,958	20	352
	Trefoil.							
3rd . {	3 cuttings }	7,040	5,561½	2,636½	278	2,102½	117	427½
Total for 4 years .		28,038	17,596½	8,185	951½	7,126½	267	1,066¼
Farmyard manure .		38,720	8,015	2,869¾	336¼	2,068	160	2,581
Surplus in favour of harvest . }		—	9,581½	5,315½	615½	5,058½	107	—
Surplus in favour of manure . }		—	—	—	—	—	—	1,514¾

Thus, in a rotation of four years, the harvest exceeds the farmyard manure by 11,096 lbs. for the organic elements, whilst the manure, on the contrary, prevails over the harvest by 1,514¾ lbs. for the inorganic elements.

to other modes of culture. It will be interesting to discover the means by which the restitution is effected.

The analysis of the water reveals nothing but the existence of nitrogenous compounds like ammonia, and the nitrates, and different inorganic elements entering into the composition of plants, but no trace of carbo-hydrates analogous to the blackish matter contained in farmyard manure. Nevertheless, the average yield of a water meadow is maintained with as much regularity as that of manured lands.

The conclusion to be drawn from all this is evidently that farmyard manure gives to plants a part only of the carbon, hydrogen, oxygen and nitrogen they contain. There is always in the crops produced an excess of these four bodies, which is at any rate equal to the amount contained in the manure, and which proceeds from another source, this source being evidently the air and water: the air supplying carbon and nitrogen, and the water hydrogen and oxygen. To confirm this view I quote the example of meadow land kept in proper condition by inundation only, the crops from them being maintained at their normal amount solely by the supply of mineral and nitrogenous substances held in solution and suspension by the water, and representing only about two or three per cent. of their total weight.

It is, therefore, practice and not science that is responsible for the notion that the restitution effected by manure is only a partial one; the practice of ages proves the fact, and science shows us that the restitution is complete in the inorganic and partial in the organic elements.

Three out of the four organic elements of farmyard manure, viz., carbon, hydrogen and oxygen, have only a very secondary function; they are represented in the manure by the litter and those parts of the plants which have not been altered by the digestive action of animals, these substances possessing scarcely any fertilising value.

A striking proof of the statements concerning meadow land is furnished by geology, which tells us that the first living things that made their appearance on the surface of the globe were plants; that the immense layers of coal now being worked in order to supply us with fuel are formed from these primitive plants, that in those remote ages vegetation was far more luxuriant and plants attained greater dimensions than at present; that the calamites and lepidodendrons which formed the forests of that vanished world, and which grew to a height of about 30 or 40 feet, are represented in our present flora by such humble plants as mares' tails and club mosses only about 2 or 3 feet high.

At the distant epoch of which we are speaking the earth contained neither humus nor farmyard manure, which presupposes an anterior generation. Consequently by taking agricultural tradition in its integrity, whether farmyard manure or irrigation is employed, we are led to the conclusion that the carbo-hydrates, supposing them to be useful at all, play only a very secondary part, as meadow land on the one hand and primitive vegetation on the other unite in attesting that it is quite possible to dispense with them entirely.

But if this really is so, how are we to understand the constitution and function of farmyard manure? What is the connection between it and that law of restitution which we cannot escape from, and the disregard of which is fatal to the fertility of the soil?

This question will be better answered by the following table than by any long explanations:—

Farmyard manure, 100 parts.

Water	. . . 80	= 80 not wanted by plants.
Carbon	. . . 6·80	} = 13·29 woody fibre, the elements of which have their origin in the air and in water.
Hydrogen	. . . 0·82	
Oxygen	. . . 5·67	
Silica	. . . 4·32	} = 5·07 secondary mineral matter with which the soil is superabundantly provided.
Chlorine	. . . 0·04	
Sulphuric acid	. . . 0·13	
Ferric oxide	. . . 0·34	
Soda	. . . a trace	
Magnesia	. . . 0·24	} = 1·64 with which the soil is provided to only a very limited extent, and in which the efficacy of the manure essentially consists.
Nitrogen	. . . 0·41	
Phosphoric acid	. . . 0·18	
Potash	. . . 0·49	
Lime	. . . 0·56	

In 100 parts of farmyard manure we find, in the first place, 80 parts of water. Now water is evidently not the cause of its efficacy. We then come to 13·29 of carbon, hydrogen and oxygen represented by the remains of the litter and that part of the animal's food which has not been disorganised by digestion. The meadow land again points to the fact that the active principle of manure does not reside in these particular compounds.

We further find in the manure under consideration 5·07 of silica, chlorine, sulphuric acid, ferric oxide, soda and magnesia, which are of very little value in agriculture, for the simple reason that the worst lands are almost always superabundantly provided with them.

There remains finally 1·64, or in round numbers 2 per cent.

of the four bodies, nitrogen, phosphoric acid, potash and lime, of which chemical manure is composed, and which we find only in the waters which irrigate meadow land, and which alone nourished the plants belonging to the early ages of the world's history.

In what, then, do chemical and farmyard manures differ? Simply in form, in volume and in composition; but this difference is of small importance, seeing that the excess is useless for fertilising purposes.

Have you a doubt remaining as to what I said respecting the secondary mineral substances, silica, chlorine, ferric oxide, &c.? You may perhaps think it arbitrary to exclude them from chemical manures, and to question their good effects in farmyard manures. I must remain faithful to the plan which I have traced out for myself, therefore I may not call to my aid the testimony of direct experiments. I must borrow all the materials of my demonstrations from facts which are anterior to us, and these facts we obtain by comparing the composition of the farmyard manure of the crops and of the land, taking the acre as the unit of comparison. Let us compare the manure and crop of one acre with a layer of arable land spread over the surface of an acre, and see where this comparison will lead us. We learn from it that the land contains the constituents of the second group in enormous quantities, whilst they are only to be found in small proportions in the crop and in the manure.

In suppressing the mineral constituents, therefore, we are guilty of no arbitrary act; we only do for the land what we did in the case of the air and rain, when we were speaking with reference to carbon, hydrogen and oxygen.

You see what we possess in common with the past, in what we continue its work, and in what we differ. Our common basis is the necessity of restoring certain agents to the land. In past ages the intrinsic nature of these agents was not known, but guided by observation our ancestors turned their attention to the three great sources of fertility, manure, fallow land and irrigation.¹

We recognise the correctness of the principle, but we dispute the necessity of adhering to the methods of the past. These methods are not absolute, but are correlative to a determined social condition. A particular system of agriculture which is suited to the ideas, the economical conditions, the price of labour, the interest of money, and the

¹ It will be understood that the author refers not to sewage irrigation, but to the overflow of streams and rivers, which of course enriches the low-lying meadows at the expense of the uplands and hillsides.

burdens of the population at one period, may not be found suitable at another.

One point alone remains unchanged, viz., the necessity of giving back to the soil a part of what it has lost during the growth of the crops. As to deciding whether farmyard or chemical manure can be best employed it is quite a secondary matter, provided the law of restitution be observed. However, as in this matter it is necessary to be clear and precise, I unhesitatingly affirm that in the majority of cases chemical manures offer more advantages than farmyard manure, and that the latter ought never to be used except in conjunction with the former. The reason for this joint use will be given afterwards.

I have already demonstrated in my first lecture that the most valuable portion of farmyard manure is the liquid part, which is almost entirely made up of the animals' urine; we must therefore inquire into its composition.

There is, in the first place, and in considerable quantity, a crystallised body in which nitrogen is present in the proportion of one-third of that contained in the food of the animal. This is urea, which is nearly allied in its chemical nature and fertilising properties to the salts of ammonia.

Besides urea we find uric and hippuric acids, both rich in nitrogen and possessing great fertilising power; also phosphoric acid combined with lime,¹ and magnesia, and potash salts.

Lastly, there is albuminoid matter which separates spontaneously from the urine when it comes in contact with the air, and which in decomposing determines the conversion of urea into carbonate of ammonia. The uric acid itself participates in this transformation, and, finally, the fermented urine may be represented by ammonia, phosphates and salts of potash.

Now, of what are chemical manures composed? Of ammonia, phosphates, and other salts of potash and lime. There is, therefore, identity of composition between the most active portions of both farmyard and chemical manures.

There remains, it is true, the solid portion of the dejections; these are very slightly active when first produced, but they acquire great efficacy by the decomposition they undergo when brought into contact with the air. This decomposition is a sort of continuation of the work of digestion, and results in the conversion of the nitrogen into ammonia

¹The phosphoric acid eliminated by the herbivora appears rather in the solid excrements than in the urine, except the diet of the beasts contains an abundance of soluble alkaline phosphates.

and nitrates, the mineral matter contained in the excretions being at the same time rendered more soluble.

Consequently the last argument that could have been brought in opposition to us is demolished by the most rigorous analysis of the urine and the solid dejections.

No difference then exists between chemical and farmyard manure, except with regard to appearance and bulk; but if this is the case why should we be condemned to produce farmyard manure at great cost and trouble if chemical manures can be procured more easily? It is vain to bring forward the mechanical action of farmyard manure, for the fertilisation of meadow land without its aid proves that this is not indispensable.

But it may be said, if the use of chemical manures finds its justification in the past, where is its novelty? Here we must guard against confusion.

To record the history of the past, as I have just done, I have been obliged to have recourse to the teaching of chemical manures in order to give their true signification to certain facts which history has handed down to us. It was formerly the practice to comprise everything under the one watchword, "plenty of farmyard manure"; and the regions of the South, where scarcely any fodder grows, were subjected to the same treatment as the low plains of Normandy and Cottentin, where pasture land abounds.

The lessons we learn from the use of chemical manure, on the contrary, are as follows: Give back to the land more phosphoric acid, more potash, more lime, and half the nitrogen taken away from it. If the district is favourable for the breeding of animals, keep cattle, and return to your land by means of farmyard manure what has been drawn from it. If, however, the locality is unfavourable to pasture land, we are told to produce only as much farmyard manure as is strictly necessary for the preparation of the soil and for utilising the waste parts of crops which cannot be sold, making up any deficiency by laying in a stock of chemical manure. The law which governs profitable production obliges us to manure liberally but economically, and conforming to the rules which I shall hereafter point out.

In the past all cultivation depended on two inflexible conditions—a certain equilibrium between pasture and cereals, and an almost invariable order in the succession of crops; but owing to the permanent introduction of chemical manure the farmer need no longer be fettered with these conditions. The one end and aim is to make as much profit as possible; and,

free from all restraint, he can speculate at will either in cattle-breeding or the sale of fodder.

Adopting the system of free rotation, no other law is recognised but that of returning to the land the phosphoric acid, potash, lime and nitrogen we have abstracted from it. The source of this restitution matters little ; it is a money question, not an agricultural one.

In order to prove the truth of what I have just said, it is only necessary to show how science has succeeded in understanding the forces of which plants are the seat, in defining the *rôle* and pointing out the function of all the agents which unite in their formation.

But this fresh inquiry must be reserved for the next lecture. In the present one I have simply wished to examine the history of the past by the light of contemporary science.

I have endeavoured in dealing with this subject to avoid any spirit of controversy. But my task is only half-finished ; it still remains for me to lay before you the necessities of practice, and show you that if agriculture by its mission affects the most important interests of the community, the method of carrying out its principles converts it into a problem which the science of our time may claim to have the signal honour of solving.

I have, in the above review of the past history of agriculture, allowed the facts to speak for themselves, without in any way forcing their testimony. But another task yet remains to be done which is more familiar to me, viz., to ascertain from whence plant life is derived, and what are the acts in which it is summed up, and then to leave you to judge of the proofs furnished by experience, and of the results obtained by agriculture. You will then be able to decide whether the new doctrine is to be condemned and rejected, or whether by your suffrages you will henceforth confirm and strengthen my confidence in the future with a conviction equal to my own.

LECTURE VIII.

PLANT PRODUCTION.

WE will now leave the traditions of the past and apply ourselves to the consideration of the conditions of plant life, its causes, remote or proximate, its activity, the agents which produce it, and its products.

It has already been said that plants are formed of fourteen chemical elements. Now, whatever may be the origin of these fourteen elements, and the form under which they are absorbed by plants, it is necessary, in order to explain vegetation, to produce plants by their aid, without any mysterious or indeterminate condition.

The great problem to be solved is to manufacture a plant as we manufacture soap, litharge, or sulphuric acid, by making use of the peculiar force resident in the seeds, as we do elsewhere with steam or electricity. To render its solution positive and beyond doubt, I selected for the soil calcined sand, which is, as we know, pure silica; it was watered with distilled water, which, as we know, is pure water; and filled into pots of unglazed china, which, as an extra precaution, had been previously dipped into melted wax, in order to prevent the formation of those saline exudations, with which the surface of all pottery becomes covered when it is exposed to moisture.

By this arrangement a simple mechanical means was arrived at of affording a support to the roots of the plants and a medium permeable to air and water without, however, supplying them with any nutritive element. It is, in fact, the elementary soil reduced to the last degree of poverty, but surrounded with numberless precautions to shield it from all accidental causes which might disturb the simplicity of the conditions.

In a soil like this what becomes of a grain of wheat? It germinates as in good ground, but the plant which springs up shows by its miserable state the poverty of the conditions in which it has been reared. Still this plant manifests its activity, it goes through the regular cycle of its evolution, it

even yields seed, very poor and stunted it is true, but the final result is always attained, viz., that for 15 grains weight of seed a crop of 90 grains is obtained.

Thus in the calcined sand, from which all foreign matter has been excluded, the plant, which has been fed only with the elements contained in water and the atmosphere, gives seed and produces a crop weighing 90 grains, showing an increase of 75 grains, derived from the carbonic acid of the air and from the hydrogen and oxygen which have their source in the irrigating water.

Thus the air, by means of its carbonic acid and water, through its two constituent elements hydrogen and oxygen, contributes in a considerable degree to the formation of vegetable matter. But they play a more important part than this experiment would lead us to suppose, decisive as it is, for even in fertile soils it is from the air and water that plants draw essentially the carbon, hydrogen and oxygen, which form, as I have already said, $\frac{1}{10}$ th of their vegetable substance.

To confirm this result the action of all possible carbonaceous substances has been tried. The effect has always been negative. As a first attempt some carbon was added to the calcined sand, and, in order to obtain this carbon in a state of purity, recourse was had to some crystallised sugar, which was calcined in platinum vessels hermetically sealed. The result of this addition was absolutely *nil*.

In sand a crop of 90 grains had been obtained. In the sand to which carbon was added the weight of the crop was likewise 90 grains.

A priori it was easy to have foreseen this. The carbon, being insoluble in water, in no way increased the fertility of the calcined sand.

We then asked ourselves what would be the result of adding to the sand carbon in combination with hydrogen and oxygen.

The most varied materials containing carbon and hydrogen were then tried, such as straw, cellulose, gums, starch, oils and alcohol.¹ None of these materials showed the slightest action.

The idea then occurred to me of trying these same materials after their conversion through contact with air into the state of the blackish product which essentially forms humus, to which substance the ancient agricultural theories attributed such an important part.

In order to procure humus in a pure state, and produced solely from the alteration of a material of vegetable origin, I

¹ A moderate dose of alcohol checked the development of the plant.

repaired to the department of the Landes, and leaving the drifts where the sand is as white as snow, I advanced into the interior of the country till I reached the ancient pine forests, where every year the fallen leaves produced, by the alteration which they undergo, that blackish material, soluble in potash, which is the essential character of humus. The sand of the Landes was taken then as representing a medium inert in itself corresponding to the calcined sand, but which, however, contained humus in the formation of which no kind of manure had played a part. Under these new conditions what was the result? Exactly the same as in the experiment with the calcined sand: 90 grains of produce. The addition of humus had produced no appreciable effect.

You will remark that in all this there is no question of theory or doctrine, but simply experimental proofs calculated to convert abstract conceptions into absolute facts.

Thus the soil, which is reduced to a simple mechanical support for the plant, receives no improvement by the addition of carbon or substances containing hydrogen and carbon, either intact or decomposed, nor even from humus itself, which was an unexpected and singular result.

The three elements, carbon, hydrogen and oxygen, represent in themselves 95 per cent. of the weight of plants. The addition of these three elements under the most varied forms was always without effect.

The time had now come to try the last of the four organic elements, nitrogen, thus beginning a new series of experiments. To the calcined sand was then added some gelatine, which contains nitrogen, together with carbon, hydrogen and oxygen. This time an important change took place in the phenomena.

The plants, which till then had been of a pale green colour, showed, by the brighter shade of their foliage, an increase of activity. It had seemed for the moment that vegetation was about to become vigorous and active. But these hopes were blighted, for the crop was only 130 grains instead of 90. The addition, therefore, of the four primary elements, which in themselves represent more than nine-tenths of the substance of plants, had only a very insignificant effect. Up to this point vegetation is very languid and precarious, but the plants always go through the entire cycle of their evolution, and, moreover, produce a rudiment of seed.

Although surprised at the small results of these first experiments, we could not stop there. The inorganic elements must of necessity be submitted to a similar trial. A new

experiment was, therefore, instituted, and this time all the inorganic elements were added to the calcined sand.

Phosphorus was supplied in the state of calcic phosphate and magnesian phosphate, sulphur as calcic sulphate, chlorine as sodic chloride, lime in the state of carbonate, silica in that of potassic and sodic silicate, and iron and manganese as sulphates.

Again wheat was sown, but scarcely any better result was obtained than in the former experiments. The plants were weak and shrivelled, the stalk not larger than a knitting-needle, and only about six or eight inches in height, whilst the ear contained only two small and ill-formed grains.

One last experiment still remained to be tried, and this was to mix nitrogenous matter with the mineral matter. This was done, the contrast being striking and the success complete. The plants appeared not to have suffered in the slightest degree, but attained the same development as they would have done in good soil; the leaves were broad and beautifully green, and the stalk more than four feet in height, whilst the ear was well formed and filled with grain. The conditions of perfect plant nutrition had thus been realised in calcined sand.

This experiment is one of great importance, both on account of its practical result, and also because it brings to light a new principle the general application of which is destined to become one of the canons of agricultural art. This rule may be expressed thus: a nitrogenous material, which by itself is almost without action on vegetables, imparts a sudden activity to ten other substances (inorganic elements), which without its concurrence would have produced only a very slight effect.

Here the salutary effect arises from combination. It is to this that the definition *principle of collective force* has been given, as calculated to determine its true character, and prepare the mind to generalise its application.

Important as this result unquestionably is, we must not rest here. Having discovered the conditions that insure the activity of the inorganic elements, we must now proceed to inquire into the degree in which they are efficacious, and the function peculiar to each of them.

It was now a question of disentangling these new phenomena, and the way to do so was plainly marked out. The intervention of nitrogenous matter having been acknowledged necessary to insure the activity of the minerals, a new series of experiments in calcined sand was instituted. This time a fixed and invariable quantity of nitrogenous matter was

mixed with the sand as a constant ingredient, and all the other mineral ingredients were added by turns, except one. The experiments were repeated as many times as there were different mineral ingredients, in order that each might be excluded in its turn: the deviation between the crop obtained with the ten mineral ingredients, and those in which they were reduced to nine, being taken to indicate the degree of importance of the suppressed ingredient.

We will now proceed with these fresh experiments. A nitrogenous material and all the mineral ingredients, without any exception, are added to the calcined sand. The plants prosper, and 22 wheat grains yield plants weighing 337 grains, and in some cases 400 grains.

A second experiment is then performed under the same conditions as the first, except that the phosphates were omitted. What now happens? The plants spring up, form their first leaves, which, however, soon become yellow, wither and die, and the yield is of course nothing.

We have proved that, if the nitrogenous matter is retained, the plants become miserable and stunted, but they do not die. Death, on the contrary, invariably follows the addition of the mineral matter from which the phosphates are excluded. This proves conclusively that the phosphates fill two distinct functions, viz., they aid themselves in the nutrition of the plant, and determine the beneficial action of the other mineral ingredients. Their function is, therefore, more important than that of the other mineral ingredients, since to their own peculiar action is added a secondary derived effect, that of determining the assimilation of all the other mineral ingredients.

In the next experiment potash was excluded. As soon as this alkali is lacking in the soil, the plant suffers greatly; the stalk, instead of growing vertically, bends as if it wanted solidity. It does not die, however, but the yield scarcely reaches 92 grains.

From a chemical point of view the closest resemblance exists between potash and soda. In nearly all the natural compounds which contain potash, soda is also found, and in order to distinguish between the two alkalies, a close acquaintance with the intricacies of chemical reactions is necessary. But to the plant there is a vast difference, for in the experiment in which potash was suppressed, and where vegetation suffered so much, the soil was largely provided with soda. It is then an acknowledged fact that soda cannot supply the place of potash.

Magnesia was submitted to the same method of ex-

clusion. The effects were as disastrous as in the case of potash.

There are some plants, particularly buck-wheat, on which the effects of this suppression are immediate. On wheat they are manifested a little more slowly, but are still very significant. When magnesia is excluded from the soil the yield falls to about 123 grains instead of 337.

In a sandy soil formed exclusively of silica, but in an insoluble state, the omission of soluble silica is very prejudicial to vegetable activity. From 337 grains the yield dwindles down to about 120.

The suppression of the lime produces a less sensible effect: the yield is then about 307 grains, instead of 337.

For reasons which will presently be given, we shall, whilst recognising in principle the utility of sulphuric acid, chlorine, ferric oxide or manganese, pass over their effects in silence. Such an investigation would be of no practical use in furthering the object we have in view. Let us stop at this point, and look back along the road we have traversed.

We have seen that in the most barren soil that can possibly be imagined, and with the resources alone that the embryo finds in the substance of the grain, plants are formed which go through all their natural phases, although they always remain in a weak and stunted state.

This first result is followed by another, viz., that no appreciable effect is produced by the introduction of carbon, hydrogen and oxygen into the soil, even in the state of humus, neither is the crop in any degree affected.

Again, the action of all the mineral ingredients combined was tried, excluding, however, the nitrogenous material; their effect was almost null; a sudden change was, however, produced as soon as the nitrogenous matter was added to the mineral ingredients. In this artificial soil crops were then obtained which would in all respects bear comparison with those grown in good soil.

It is then incontestably proved that in a soil composed entirely of sand, a few chemical products were sufficient to place it on a level with fertile land.

Having arrived at this point, we analysed the phenomena more closely, testing the separate action of all the minerals—phosphates, silica, potash, &c., and defining the function peculiar to each.

The fundamental conditions of plant growth being cleared up and defined by the preceding experiments, we advanced still another step. Leaving the culture in calcined sand, we extended our investigations to various natural soils.

On submitting them to the same experimental system, we found that whatever might be their dissimilarity there was a distinct line of demarcation between the phenomena produced in them and those observed in the calcined sand, for to render vegetation flourishing in the latter material a nitrogenous material and ten mineral ingredients were required, whilst in natural soil, however poor it might be, a nitrogenous ingredient and three mineral ingredients only—phosphoric acid, potash and lime—are sufficient. The yield is maintained at the same level as when sulphur, silica, soda, magnesia, iron and chlorine are added, which explains to you why I did not go further into the effects of bodies.

Experience shows, therefore, that the four ingredients—nitrogenous matter, phosphate, potash and lime—are the only ones that need be admitted into manures.

For myself I have never found any natural earths in which, with the help of these four substances, it was not possible to obtain a yield comparable to that obtained in the most favoured soils.

This result is possible because the poorest soils are provided with the seven mineral ingredients excluded from normal manure, whilst it is not necessary to furnish carbon, hydrogen and oxygen, as the plants receive these elements from the atmosphere.

We must not therefore confound the requirements of a plant grown in calcined sand, which affords no nutrition, with those of a plant grown in natural earth. In calcined sand or an equivalent medium, ten mineral ingredients and a nitrogenous material are all required, whilst, on the contrary, in natural soil a nitrogenous material and three mineral ingredients are sufficient.

For practical agriculture a nitrogenous ingredient and three mineral ingredients are all that are wanted.

When, in 1861, I advanced this proposition in the course of my instructions at Vincennes, I accompanied it with a declaration which, to avoid all equivocation and unfounded interpretations, I think it well to reproduce.

“I give the name of normal manure to the mixture of phosphate of lime, potash, lime and a nitrogenous material.

“In so doing, I do not intend to deny the utility of the other mineral ingredients. I exclude them from the manure, because the soil is provided with them naturally. Why, therefore, give to the manure that which adds nothing to its effect, and complicates what may be rendered more simple?”

There is in all this neither system nor theory, but the

direct testimony of experience, to which we invariably appeal, and which I shall sum up in the following table:—

Calcined sand	Weight of crops
„ with addition of ten mineral ingredients	90 grains
„ „ „ nitrogenous matter	123 „
„ „ „ mineral and nitro- genous matter	138 „
	275 to 337 „

If we pass from these fundamental data to the function of each mineral ingredient in particular, the results are neither less precise nor less explicit. The soil being provided with nitrogenous matter as a constant ingredient:—

With all the mineral matter, except phosphate	Weight of crops
„ „ „ „ potash	<i>nil</i>
„ „ „ „ magnesia	138 grains
„ „ „ „ soluble silica	107 „
„ „ „ without any suppression	123 „
	275 to 337 „

But in nature no earth is found formed of calcined sand alone. Arable land contains sand, clay, limestone and humus. Now, it would be very interesting to know whether the phenomena which have just been brought to your notice, and of which the Vincennes field is a practical demonstration, would also be produced with the intervention of these new bodies just as they have been in calcined sand also.

There is only one way of deciding this question, viz., to again have recourse to experiments, recommencing all the series which you already know, keeping as invariable ingredients the fertilising combinations before employed, but using in place of the calcined sand mixtures of sand and clay, sand and limestone, sand and humus, then more complex combinations—such as sand, clay and limestone; sand, clay and humus; and finally, combining sand, clay, limestone and humus—thus reproducing the most essential characteristics of the composition of natural soil.

What is the result of these fresh trials? We find that in a mixture of sand and clay, or of sand and limestone, the yield is the same as in sand alone. There is only one case in which the yield is increased, and that is when humus is added to the calcareous element.

With the help of all the mineral matter and a nitrogenous ingredient the yield rose:—

In calcined sand	to 337 grains
„ sand and clay	„ 337 „
„ sand, clay and limestone	„ 337 „
„ sand and humus	„ 337 „
„ sand, humus and clay	„ 337 „
„ sand, humus, clay and limestone	„ 475 „

It will be seen that as soon as humus and carbonate of lime are associated, the yield increases from 337 to 475 grains. Whence the conclusion that humus performs an important function which is evidenced by a considerable increase in the crop.

But in what way does humus act? Is it absorbed in kind? No. It simply acts in an indirect way by favouring the solution of calcic carbonate; and this is so true, that if humus is excluded and the calcic carbonate replaced by more soluble calcareous salts, calcic sulphate and nitrate especially (in which nitrogen is reckoned as nitrogenous matter), a yield is obtained which increases with the solubility of the calcareous salt until it reaches 475 grains. But calcic nitrate being unsuitable on account of its cost¹ and extreme deliquescence, I performed many experiments with the idea of substituting for it in chemical manure a mixture of peat and calcic carbonate. But to obtain any appreciable effect, I was obliged to use peat in quantities of from 2 to 4 tons per acre, which rendered the method impracticable, and confirmed the experiments I had previously made on a small scale, inasmuch as the soil of the Landes which I used contained from 4 to 5 per cent. of black matter soluble in potash.

In such an emergency, my decision was quickly made. Abandoning the idea of using peat and analogous products, I not only redoubled my efforts to form a perfect manure, but I also used all my influence in the agricultural world to institute numerous experiments with chemical manure in soils notoriously devoid of humus, such as the chalky soil of Champagne, the sand of the dunes of Holland, or those of Campine, and everywhere I had the satisfaction of seeing the crops, even in the worst soil, rise to the same level as those grown in alluvial soils, noted for their productiveness, and fertilised with farmyard manure, that is to say with the help of humus.

I will here revert to an example given in a former lecture, as it is very complete and decisive.

In the rocky part of Champagne, and on land worth not more than from 3*l.* 4*s.* to 4*l.* 16*s.* per acre, which had been cleared, expressly, two parallel experiments were made, 97 cubic yards of farmyard manure being given to the land in the one case, and 1,056 lbs. of chemical manure in the other. To the chemical manure humus was added with the following results: With farmyard manure only 14½ bushels of grain per acre were obtained, and with the chemical manure 36½.

¹ Calcic nitrate is now made at a cheap rate on a large scale, the necessary nitrogen being obtained from the air (see appendix).

An important and incontrovertible fact here presents itself, viz., that harvests very superior to those obtained with farmyard manure may be obtained with pure chemical products, to the total exclusion of organic matter. But here an objection presents itself.

How, it will be said, is it possible that calcined sand can show itself equal to a mixture of sand, clay and limestone, so that there is no difference between them in respect to crops, when the universality of agricultural facts attests the contrary? Does not everybody know that the classification of land into heavy land, light land, rye land and wheat land is perfectly judicious? I do not contest the legitimacy of the objection, but the explanation is easy. In special experiments the plant is subject to incessant care, it is sheltered from the too great action of the sun, it is watered several times a day, and suffers neither from an excess of humidity nor drought. It is not therefore grown under natural conditions. If the plant is exposed to bad weather, and to all the accidents arising from it, then according as the land is light or heavy, the quantity of water retained in the soil varies very much, and the conditions in which the plant is placed are modified in a corresponding degree. Hence it follows that the variations in the crop according as the earth contains more or less clay are not accounted for by the part which clay has played in the nutrition of plants, but the more or less favourable conditions as to the humidity of the soil in which this substance has placed them.

In all the facts I have previously referred to, I have abstained entirely from theory. My supreme ambition has been to raise plants in a soil into which no foreign element was admitted by means of chemical products, and to subject the experiments to constant control and certain verification.

This has been accomplished, and the facts I have just given are the result of sixteen years' arduous work, to say nothing of the practical difficulties which for a long time stopped my path. It is almost impossible to credit, except by personal experience, how difficult it is in theoretical agriculture to avoid the intervention of foreign influences.

All clays and pottery yield to water, traces of salts of lime and potash, chlorides and sulphates; and slight as they are, these exudations are sufficient to disturb the true signification of the phenomena.

I determined to use only pure substances, and to set them to work in a soil formed exclusively of silica. I formed no conclusion except from direct testimony given by the plants themselves, and I did not definitely accept even these proofs,

until I had ascertained by an analysis of the crops that no foreign matter had entered into the soil or plant. My statements are therefore free from any chance assertion or disturbing influence, or indeed from anything that might have escaped a less rigorous and scientific demonstration.

This, however, is not all. Normal manure, composed of four ingredients, phosphoric acid, lime, potash and nitrogen, is sufficient, as has been said, to render the most barren soil fertile; still these four bodies are not of the same degree of utility to all plants indiscriminately, but according to the nature of the plant, one of them exercises a preponderating influence over the other three, and thus constitutes itself the regulator of the crop. For instance, with wheat, beetroot and hemp, it is the nitrogenous matter which by preference influences the crop. Were we to use double or treble the quantity of phosphate, potash or lime the yield would not change, but if we vary the quantity of nitrogenous matter the crop is immediately increased or decreased in proportion; an evident proof that with respect to the three crops above mentioned, it is the nitrogenous matter which really fills the most important office.

But another, and equally important, result must not be lost sight of, viz., that if the three mineral ingredients are omitted from the normal manure and nothing left but the nitrogenous matter, its efficacy is almost entirely lost. We therefore see that the aid of phosphoric acid, lime and potash is absolutely necessary, and if it happens that the use of the nitrogenous matter without any admixture of them succeeds, it is because the soil is naturally supplied with these three mineral ingredients.

Passing from wheat and hemp to potatoes and leguminous plants, we find that nitrogenous matter is only of secondary importance; here potash becomes the most important ingredient, as is also the case with trefoil and lucern. With sugar-cane, maize, millet and turnips, calcic phosphate is the dominant constituent.

We are therefore led to the following conclusion: that by the aid of simple chemical products, and by the exclusion of all unknown substances, a maximum crop may be obtained from all plants, in any place and in any condition of soil; further, by varying the quantity of these products, the work of vegetation may be regulated almost like a machine, the usefulness of which is in proportion to the fuel it consumes.

Vegetation imperatively demands fourteen elements, but it is only necessary to give four to the land, as the rest are obtained from the air, the soil and the rain. Four great

sources, therefore—the atmosphere, the soil, rain and chemical manure—combine for the maintenance of plant life, and each of these has its special function. But although the work of vegetation requires the co-operation of the four at the same time, man has only to work with two, the soil which he tills and makes light, and the normal manure with which he fertilises it.

A peculiar and unique characteristic of agricultural production is that it yields more than has been expended on it, because all the forces of nature, heat, light, air, dew and rain, add their invisible aid to human labour; this indeed plays only a small part in the majestic harmony of nature, still it is a part that almost requires man to possess the sovereign faculty of commanding the elements, which sometimes would seem to be leagued against him.

There is nothing arbitrary in these conclusions; they are derived, not from supposition or theory, but from the results of experience.

We will now pass from this dogmatic exposition to an experimental demonstration. To this end we shall be confronted with crops which have received only chemical manures for thirteen years. We shall judge of their condition. If we then study each of those in which one of the four ingredients of normal manure has been omitted, we shall see the truth of the proposition, that, according to the nature of the plant, there is always one ingredient which fills a more important function than the rest. And by these means conclusive proof will be given of the two fundamental data, that in the formation of plants there is no longer any mystery, but that the active agents in that formation are as well known to us as those used in the manufacture of chemical products.

The methods employed differ, the forces brought into play are not the same, still the results are identical, since, by starting with strictly defined bodies, we succeed in producing, by the aid of plants, other substances equally well known, such as oil, sugar, starch or gluten, alimentary seeds, fodder, colouring or textile matters. And with what are these produced? In every case with the four ingredients of which we have before spoken, the quantity of which it is only necessary to vary.

And now that the bases of the new doctrine are familiar, we will proceed to demonstrate the proofs obtained by experience.

LECTURE IX.

ANALYSIS OF THE SOIL BY THE PLANTS THEMSELVES.

THE present lecture will be of an essentially practical character. We shall not concern ourselves with theories or systems, but simply set ourselves to analyse the soil, and in order to acquire certain data on the nature of manures, to which it is expedient to have recourse under all circumstances, we shall define what the soil contains and what it lacks for the requirements of agriculture.

It will be remembered that in the last lecture we proved experimentally the necessity of classifying the constituents of the soil according to the special function they perform, of separating those which serve simply as a mechanical support to plants, from those which contribute to their nutrition, and whose substance at a given time becomes a constituent part of the plant itself.

The following table gives, in a practical form, an accurate summary of this part of our researches:—

Soil {	{	<i>Mechanical Constituents</i>	{	Sand Clay Limestone Gravel
	{	Active assimilable constituents	{	Organic { Ammonia Nitrates Phosphoric acid Sulphuric acid Chlorine
			{	Inorganic { Silica Potash Soda Lime Magnesia Ferric oxide Oxide of manganese Humus
		Assimilable constituents in reserve	{	Organic detritus Indecomposed minerals

We see here that there are, in the soil, three orders of constituents, mechanical constituents, active assimilable constituents, and assimilable constituents in reserve.

The mechanical constituents have in reality only a passive function. They serve as a basis for the plants and keep them in their places, but they do not by their substance aid in their nutrition. They are represented by sand, limestone, clay and gravel.

We next have the so-called active assimilable constituents, which always occur in very small quantities, compared with the former; for whilst the mechanical constituents represent 95 per cent. of the substance of the soil, the active assimilable constituents represent only a few hundredths or thousandths of the whole. Nevertheless it is in them that the productive power of the soil is essentially vested.

We come in the last place to the assimilable constituents in reserve; these share the passive functions of the mechanical constituents, but are also susceptible of contributing, at a given moment, to plant nutrition; this faculty they owe to the products resulting from their decomposition. As an example I may mention the detritus of animal or vegetable origin, which can only aid in the nutrition of plants by undergoing a change of nature. The same may be said of the silicious rocks, such as feldspar and feldspathic sands, which belong to the category of mechanical constituents as long as they preserve their integrity, but which, by the combined action of frost, heat and the carbonic acid and oxygen of the air, are first disintegrated, and then decomposed; which means that a certain portion of potash, lime and soluble silica is given to the soil, and its richness thereby somewhat increased.

If we prepare an artificial soil by combining the three categories of substances above mentioned, varying the proportions of the mechanical constituents, sand, limestone and gravel, from 4 to 10, or even 20 per cent. of the whole weight, we shall find that the fertility of the soil is not affected, but that, on the contrary, if we increase or diminish by a hundred-thousandth part the weight of nitrogen, ammonia and nitrates, or by a ten-millionth part the weight of potash or phosphoric acid, a sudden change is produced, and the crop increases or diminishes in proportion, just as the production of steam in the boiler of an engine is regulated by the amount of fuel burnt in the furnace.

The methods by which we succeeded in establishing these distinctions and in showing the contrast between the mechanical and assimilable constituents of the soil were very simple.

The land was not analysed, but artificial soils were formed with pure substances, and many interesting experiments performed.

The office of the mechanical constituents is, as has already been said, to hold the plants in the earth, and to form that remarkable medium, at once compact, mobile and permeable, into which the finest roots can spread out, through which water can penetrate freely, and air circulate without obstacle, carrying to its remotest depths their powerful and vivifying properties.

The assimilable constituents have no influence on the physical properties of the land, but serve to nourish the plant and to regulate the activity of its growth. I will add nothing to what I have already said of the active assimilable constituents in reserve; they are at first mingled with the mechanical constituents, but afterwards become by their decomposition a source of assimilable constituents.

By the light of these distinctions, and by reference to the table in which they are summarised, it is easy to understand why the older chemists, working according to the methods in use in commercial assays, always failed to show the true agricultural value of the various soils, and why even the most eminent amongst them were baffled.

As an example of this, I may mention one of the greatest names of bygone science, Sir Humphry Davy, to whom we are indebted for the discovery of the alkali metals, potassium and sodium.

Starting with the idea, a very correct one in itself, that soils which belong to different geological formations often possess the same degree of fertility, Davy thought that by comparing, constituent by constituent, the composition of a certain number of earths presenting this double character of being equal in an agricultural point of view, and of belonging to different pieces of ground, he ought, side by side with inevitable dissimilarities, to be able to find in all of them the presence of certain agents, constituting the source and condition of their equal fertility. Six samples of earth from different sources, and all renowned for their fertility, were analysed by Davy, and the result was that he had to abandon his theory.

If you will examine the table in which the results of these six analyses are given, you will find there nothing but contrast and opposition; it is impossible to discover the slightest analogy in the composition of the soils, although all six possess the same degree of fertility.

Analyses of Soils by Sir Humphry Davy.

Source of soil	Sand and gravel	Silica	Alumina	Calcic carbonate	Magnesian carbonate	Ferric oxide	Salts and organic matter	Calcic sulphate	Moisture	Loss
County of Kent .	66·2	5·2	3·2	4·7	0·7	1·2	8·0	0·5	4·7	5·2
Norfolk . . .	88·9	1·6	1·2	6·9	—	0·3	0·5	—	0·3	—
Middlesex . .	60·0	12·8	11·6	11·2	—	4·4	—	—	—	—
Worcestershire .	60·0	16·4	14·0	5·6	—	1·2	2·8	—	—	—
Vale of Teviot .	83·3	7·0	6·8	0·6	—	0·8	1·3	—	—	—
Salisbury . .	9·1	12·7	6·3	57·2	—	1·8	12·7	—	—	—

Compare these six analyses constituent by constituent, and you will see that the proportion of sand varies from 9 to 90 per cent., that of soluble silica from 1 to 16 per cent., calcic carbonate from 0·6 to 57 per cent., and so on. None of these earths resemble those that preceded, or those that follow after—all differ, and each contrasts strongly with the other, and yet, as I have said before, each separate earth possesses the same agricultural value.

The present methods of chemical analysis are then in complete disaccord with plants, which, as you have doubtless observed, give a totally different result. How can we explain this apparent contradiction? Nothing is easier. It will suffice if we consider the classification of vegetable soils which I have given, founded upon my own experience, where the ground consisted altogether of mixed soils. What says this table? That the mechanical constituents affect the degree of fertility of the soil only indirectly, that their function is eminently passive, that, notwithstanding their utility, they are in reality only like the coarse vein-stone with regard to the needs of plant life. This is easily explained. What light did the analysis of Davy throw upon this question? He took into account only the mechanical constituents, gravel, sand, clay and limestone, without inquiring into either the actual assimilable agents which are the actual source of production for the time being, or the assimilable constituents in reserve which are the safeguards for the future. The silence of Davy on these points plainly shows the failure of his theory, but there is nothing that can surprise us in this result. In his day only the most incomplete notions were held respecting the composition of plants and the agents concerned in their production, and if Davy did not possess more perfect knowledge it was because science was not sufficiently advanced to permit of his doing so.

A fresh difficulty now arises. The chemists of the present day are perfectly acquainted with those constituents that serve to maintain plant life, and whose presence in, or absence from, the soil increases or lessens the degree of its fertility.

It appears, then, that what Davy was unable to accomplish the chemists of our time have successfully achieved. And yet if we examine a collection of the analyses of soils which have been made during the last ten years, we shall find that they have taught us but little that is essential from an agricultural point of view—nothing in fact that we can apply to a practical purpose. This declaration from me cannot fail to surprise you. Let me therefore proceed to justify it.

Here is an analysis of a soil made by an eminent mining engineer, M. Rivot. Everything is here indicated, both mechanical and assimilable constituents.

*Analysis of a Soil in the vicinity of Chalons-sur-Marne, by
M. Rivot.*

MECHANICAL ANALYSIS.

Sand and gravel	42.25
Fine material	52.50

CHEMICAL ANALYSIS.

Organic matter	1.80
Hygrometric water	2.70
Combined water	5.92
Carbonic acid	33.20
Quartzose sand	3.10
Clay	6.00
Soluble silica	3.10
Ferric oxide	2.00
Alumina	0.15
Lime	40.50
Magnesia	traces
Alkalies	0.38
Sulphuric acid	0.28
Phosphoric acid	0.12
Nitrogen and chlorine	traces

Total	99.25
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This is certainly a most complete analysis. Nothing is here omitted, and yet it is scarcely of any more use to us than that of Davy. The testimony of agriculturists is that it does not meet any of the requirements of practice. It is, for instance, impossible by its aid to foretell with certainty the quantity, for this particular soil, of wheat or any similar crop; or to tell how many years we shall be able to cultivate it without manure, or when such necessity arises, what

particular kind of manure we shall be obliged to have recourse to. If an analysis is silent upon these points—is it of any practical utility? We have apparently arrived at a strange conclusion. I have just said that the nature of the constituents which make the soil fertile are known to us. I have shown in my former lectures that by the aid of these substances we are able to obtain as fine crops from plants grown in calcined sand as from those grown in the most fertile alluvial soil—and I declare in the same breath, that the analyses giving us the exact proportions of these same substances in any given soil are insufficient to throw light upon the principle of the agricultural question. These statements seem strangely contradictory, but the contradiction is only apparent.

Let us take a soil that contains two different kinds of sand—feldspathic and silicious, such as is found at Fontainebleau. The silicious sand is pure silica—feldspathic sand, on the contrary, is a polybasic silicate of potash, soda, lime, magnesia and iron. So long as the latter remains in its primitive state the potash and lime are useless to the plant, being unable to enter into it on account of their state of combination.

But when a chemist comes upon the scene armed with his tests, and attacks, decomposes and separates all the elements of feldspathic sand by isolating them, they attain a degree of utility which, regarding them from an agricultural point of view, they did not possess when they were firmly combined in their primitive state. Phosphoric acid leads to a similar remark. This acid may exist in the soil in three different states—as calcic phosphate, aluminic phosphate and ferric phosphate. As it exists in calcic phosphate, phosphoric acid is most valuable, but it has a far less appreciable action when it is combined with iron or alumina.

But of what use is it to us to know that the soil contains phosphoric acid, potash, nitrogen, &c., if we consider their active and inactive parts in the light of a loose and heterogeneous mass? No matter how exact in its details an analysis of the soil may be, it remains a dead letter with respect to the needs of plants, seeing that their roots are not provided with either acids, alkalies, or any other of the means of decomposing compounds which the chemist has at his disposal. My conclusion is a formal one. Chemistry is powerless to throw light upon the agricultural qualities of the soil, its resources and its needs, because it confounds in its indications the active assimilable agents with the assimilable agents in reserve, the active with the inert or neutral principles. But I wish to carry my demonstration still farther, and to do so

with greater freedom I shall choose for criticism as a last example an analysis of which I am the author, that of the soil in the experimental field at Vincennes. This analysis tells us that the quantity of available phosphoric acid amounts to $1,581\frac{1}{4}$ lbs. per acre, the quantity of potash to 2,025 lbs., and the quantity of lime to $34,674\frac{1}{4}$ lbs. per acre. These results are perfectly correct, and it is impossible to challenge their accuracy.

Here, then, is a soil very liberally provided with the three mineral constituents necessary to vegetation; nevertheless, if we try to grow wheat on it for four consecutive years, using no other fertilising materials except nitrogenous matter and ammoniac sulphate, without any addition of either potash or phosphate, we shall find that the fourth year the crops which at first were very good will be in danger of being reduced almost to nothing.

The four crops of wheat have, however, only abstracted from the earth

62 $\frac{1}{2}$	lbs. of phosphoric acid
102	„ potash
60	„ lime

where the analysis had shown that there existed

1,581 $\frac{1}{4}$	lbs. of phosphoric acid
2,025	„ potash
34,674 $\frac{1}{4}$	„ lime

thus the plant finds only a poor soil when, according to analysis, it should have found a rich one. We can only account for this anomaly by the fact that the plant shows the existence of only those elements by which it is able to profit, whilst analysis in addition takes cognisance of the whole of those constituents of the soil which are so firmly bound together that the plant is unable to separate them.

But it has been said, Why not imitate the methods of nature? Why not limit ourselves to treating the soil with water alone in order to place it in the same conditions as the plants? At first sight the idea appears excellent, and the method founded upon the irrigation of the soil a perfect one. It is, however, nothing of the sort, and a few figures will suffice to show its uselessness. It is condemned, like the first, by vegetation itself. In treating soil with hydrochloric acid, we have ascertained the presence of $1,581\frac{1}{4}$ lbs. of phosphoric acid per acre. If you treat it with water the quantity of phosphoric acid found is not more than $25\frac{1}{2}$ lbs., and the available reserve of potash only $163\frac{1}{2}$ lbs., instead of 2,025 lbs. Again if you cultivate beetroot upon this same land for

three consecutive years, you will find in the three crops 132 lbs. of phosphoric acid and $287\frac{3}{4}$ lbs. of potash. What causes this fresh anomaly? The large amount of water employed in the rapid irrigation of the soil acts in a totally different manner from small quantities of water operating by simple imbibition, the roots of the plants acting as auxiliaries. In the first case the effect obtained is entirely due to the solvent action of water, whilst in the second instance it arises from three fresh influences: the air which penetrates into the interstices of the soil, where it causes slow oxidation; carbonic acid arising from the decomposition of organic matter, which by its presence exercises a solvent and decomposing power which water alone is unable to exert; and lastly, the powers of suction possessed by the roots, which is equivalent to treating it with water under pressure.

The smallness of the quantities of phosphoric acid and potash found in the solution left after washing the soil with water is a very convincing proof of this; but there is something more. Make two parallel experiments, and sow wheat in washed soil and also in the same soil not washed. The resulting crop will be better in the first case. Here, then, is another apparently disheartening failure.

In pointing out the insufficiency of our present methods of analyses, it must not be thought that I condemn them in an absolute manner, or that I deny the possibility of arriving perhaps one day at more complete results, for nothing is farther from my thoughts. I simply wish to show things as they are, to warn you against cherishing fallacious hopes, and to fully establish this one fact—that at the present time the most laborious analysis is not able to throw light upon the most vital and essential questions of practical agriculture.¹ But if chemical analysis is powerless to help us, we can always fall back on the evidence of the plants themselves.

It now remains for me to show the manner of applying this new test. In my last lecture I laid down the principle that by means of four substances, phosphoric acid, potash, lime and nitrogenous matter, it was possible to bring the most barren soil to the highest degree of fertility. We have learnt more than this, viz., that these four substances, however efficacious they may be, only remain as long as they are associated and united one with the other, for by suppressing

¹Considerable progress has been made in soil analysis since the author's day. By using weak solutions of citric and other acids for the extraction of the soil instead of strong acids, results can be obtained which correspond closely with the fertility of the land as determined by the growth of crops upon it.

one the remaining three are often rendered inert, and frequently lose the greater part of their activity.

We have further said that these four substances are not of the same degree of utility to all descriptions of plants, but that each has a preponderant or subordinate action by turns; that for cereals, colza and beetroot, nitrogenous matter was the preponderant constituent; phosphoric acid fulfils a similar function with respect to maize, sugar-cane and swedes; whereas potash preponderates in the case of potatoes and leguminous plants. If you thoroughly understand these three fundamental propositions, you will readily see by what natural deductions we shall be able to found upon them a practical method of analysis that will be accessible to all.

Suppose, for instance, that we experiment upon the same soil with five different manures; first of all a manure composed of the four substances of which we have been speaking, and to which we have given the name of normal manure, and next with four manures composed of three ingredients only, excluding in rotation nitrogenous matter, phosphoric acid, potash and lime, and with these produce a parallel series of crops.

With the normal manure		
Manure without	nitrogenous matter	
„	„	phosphates
„	„	potash
„	„	lime
The soil without any manure		

The result will be that the complete manure produces 43 bushels of wheat per acre; manure without nitrogenous matter produces 14 bushels; manure without phosphates $26\frac{1}{2}$; manure without potash 31; manure without lime 41; and the soil without any manure only 12 bushels per acre.

The conclusion is evident and conclusive. The soil in such an instance evidently requires above all nitrogenous matter; it is provided with lime, but insufficiently supplied with potash and calcic phosphate. What analysis, I ask, be it as delicate as it is possible to conceive, will ever be able to furnish us with a series of results like this? According as the crops obtained with the incomplete manures differ from or resemble those resulting from the use of the normal manures, the conclusion we arrive at is, that the soil lacks the ingredient excluded from these manures, or *vice versâ*. To place the matter more clearly, we will append the following table, the results being those obtained in the experimental field at Vincennes:—

	Crop per acre Bushels
Normal manure . . .	43
Manure without lime . . .	41
„ „ potash . . .	31
„ „ phosphate . . .	26½
„ „ nitrogen . . .	14
Soil without manure . . .	12

I repeat, that the element lacking in the soil at Vincennes is chiefly nitrogen. But this is not all. In every soil there are two portions to be considered, the surface soil and the subsoil, the upper and under layers, and it is most important that we should have definite ideas upon this subject. We may gain the necessary knowledge very easily, by substituting for wheat some tap-rooted plant; beetroot, for instance, which buries itself in the ground to a much greater depth.¹ Submit the beetroot to a similar series of experiments, and you will obtain just as accurate information as you did with wheat, but these results relate to the under instead of the upper layers of the soil.

What do we obtain?—

	Crop per acre Tons Cwts.
Normal manure . . .	20 16 of beetroot
Manure without lime . . .	18 16 „
„ „ potash . . .	16 16 „
„ „ phosphate . . .	14 16 „
„ „ nitrogen . . .	14 8 „
Soil without manure . . .	10 0 „

With potatoes, the information gained is no less instructive and precise:—

	Crop per acre Tons Cwts.
Normal manure . . .	11 3 of potatoes
Manure without lime . . .	8 4 „
„ „ phosphate . . .	6 6 „
„ „ nitrogen . . .	5 18 „
„ „ potash . . .	2 2 „
Soil without manure . . .	2 14 „

The potato then tells us that the soil of Vincennes does not contain sufficient proportions of potash and of nitrogen, and if it shows a preference for soil that is rich in potash, it is because that substance is its dominant constituent; that is to say, it is the ingredient in manure that acts most beneficially upon that special crop.

The evidence of these two plants is not contradictory

¹The roots of wheat in a suitable soil may penetrate 6 feet and upwards, whence its power of bearing dry seasons.

but confirmatory, and you will observe how the preponderance of certain constituents gives an additional value to the same facts. In order to gather an exact idea of the richness of the under layer, or subsoil, at Vincennes, it is necessary to consider the result which was obtained at the same time with wheat and potatoes. A series of crops of wheat shows plainly that nitrogenous matter and potash are present in restricted proportions, and a series of potato crops confirms and ratifies this testimony; only with manure without potash, the crop of potatoes is feebler and comparatively smaller than that of wheat, because potash is a dominant constituent in potatoes, and only a subordinate constituent in wheat. Here, then, is a perfectly accurate system of experiments, and the information gained may at once be applied to practical use. With an experimental field, we always determine the nature of the substances useful to plants contained in the soil, and also determine in what constituents the soil is deficient, and with this knowledge we can decide what sort of manure it will be advisable to employ. Perhaps it may be objected that this method must necessarily lack delicacy and preciseness, and that it is doubtful if a plant can show all the varieties of composition presented by different kinds of soil. This objection is easily answered. The quantity of soil covering the surface of 1 acre is represented by at least 1,600 tons, and with 176 lbs. of ammoniac sulphate and $35\frac{1}{4}$ lbs. of nitrogen—that is to say, the one-hundred-thousandth part of the total weight of the soil—the crop of wheat will be increased from $13\frac{1}{2}$ to $16\frac{1}{2}$ bushels of grain per acre, and the straw from 2,640 lbs. to 3,520 lbs.

With potatoes, 176 lbs. of nitrates, of which $82\frac{3}{4}$ lbs. are in the form of potassic nitrate, suffice to raise the yield from 4 tons per acre to 7 tons 4 cwts.

When calcic phosphate is applied to a growth of sugar-cane, the effects are not less marked.

If the manure contains 528 lbs. of calcic phosphate we shall obtain 32 tons of cane stripped of leaves; but with 352 lbs. of the phosphate the result is lowered to 16 tons. What result, I ask, obtained by purely scientific means can be compared with this, whether as regards the delicacy of the method, or the utility of the information that it yields? The great value of experimental fields then lies in our being able to obtain such evidence as the latter by a series of proofs. I will briefly show you how we should proceed in the formation of such fields, according to the purpose for which they are to be used. If the results of our experiments are somewhat important, we must choose a piece of land representing the

mean fertility of the whole estate and of uniform nature, and divide it into ten plots each containing, say, a quarter of an acre, to be fertilised as shown beneath :—

No. 1	is to receive	24 tons of farmyard manure
2	12	very rich normal manure
3	ordinary	manure without nitrogenous matter
4	manure without	nitrogenous matter
5	phosphates	
6	potash	
7	lime	
8	mineral matter	
9	soil without any	manure
10		

Here is a system equal to all the exigencies of every kind of culture. Thanks to this method of growing crops side by side, we are able to follow methodically the exhaustion of the soil; that advanced guard of the field of experiments indicates with certainty the precise moment when the soil is ready to receive nitrogenous matter, potash or calcic phosphate, as the case may be. But it will be said that on every farm it may happen, as it nearly always does, that there are soils of very different nature. The experimental field of which we have just been speaking does not suffice for an extended inquiry, and in order to arrive at useful results, it is necessary to set aside an additional quarter of an acre, divided into four parts, on which to experiment with these different manures—normal manure, mineral manure and nitrogenous matter, the fourth part receiving no manure at all. With these four combinations of manure, under the condition that if necessary the trial may be repeated, we can acquire with certainty all information of which, practically speaking, we have need. The first field, by reason of its greater extent, and the more numerous and varied combination of manure that it receives, is, as it were, a centre towards which all the others must gravitate. The results given by the smaller plots are tested by those of the first field, which acts as a sort of touchstone, and in a certain measure completes and rectifies their signification. When you are once familiarised with this mode of investigation, every kind of culture becomes a source of information concerning the state of the soil—its richness or its exhaustion. Here, for instance, is an example :—

On two contiguous portions of land, say of a few square yards, sow peas and wheat without any kind of manure. This little experiment will amply suffice to ascertain if the soil contains nitrogenous and mineral matter. We have already seen that nitrogenous matter was the dominant con-

stituent in wheat, and that it was only of very secondary importance to peas, if, indeed, its action could be regarded as of any use at all to them; whilst the dominant constituent in peas was potash. You see now, by the light of these simple facts, with how much importance the experiment just quoted can be invested. If the two squares of wheat and peas are equally fine, it proves that the soil contains a sufficiency both of nitrogenous and mineral matter.

Now if the wheat becomes small, yellow and rather soft whilst the peas flourish well, it proves that the soil is lacking in dominant constituent of wheat, which is nitrogenous matter, whilst it contains, on the contrary, a sufficiency of mineral matter, and above all of potash.

We will extend the range of our observations. Lucern has roots which penetrate deeply into the subsoil. It is from these underlayers that it principally obtains the mineral matter of which it requires a large quantity. Suppose that lucern prospers whilst peas are weakly: what are we to conclude from this? That the superficial layers of soil are lacking in potash and phosphates, whilst the deep layers are provided with them; but if the two plants progress equally well, we know that the superficial and deep layers of soil are well provided with mineral matter.

You see, then, that, thanks to the exactness of the premises which we in a great part drew from our experiments in calcined sand, by the aid of pure substances and the exclusion of unknown agents, we have succeeded in acquiring ideas of an essentially practical character, which enable us to reply to the two questions—what are the useful agents contained in the soil, and what are those in which it is lacking? The more my studies are extended and completed, the more my acquaintance with the principles of agriculture is increased, and the more convinced I am that if the facts that have occupied our attention are brought down to the greatest degree of simplicity, and evidence is furnished which will permit any man possessing the most elementary knowledge of science to grasp and utilise it, then will it be made clear that we are alone indebted to the experimental field. To those who understand, it offers a guide that never misleads; and to those who doubt, it affords evidence that will always triumph even over the most systematic opposition.

If you believe that in these matters I have acquired some authority, adopt my advice, and multiply your experimental fields—which the Italians justly call “proving fields”—provide them in all our colleges, in all our elementary schools and in all our agricultural institutions; for primary schools $\frac{3}{4}$ of an

acre or an acre of land will amply suffice, and for these in particular I would advise the parallel culture of wheat and potatoes alternately. The instructor will find in the growth of potatoes a valuable addition as a food supply for his household; and in the crop of wheat a tiny golden store that will recompense him for his labours.

The fields of agricultural societies should be equal to greater exigencies, and serve for the instruction of the neighbourhood.

Four parallel plots of wheat, beetroot, potatoes and peas placed in rows, afford a practical example of the necessity of varying the composition of the normal manure for each of these four crops, not only in the number of substances of which they must be composed, but also in the quantities of each. These experiments also bring into prominence the fruitful notion that each kind of plant has its dominant constituents, a principle which is but little understood at present even amongst the learned, and show the necessity of varying the manure according to the description of plant we have to deal with, at the same time pointing out its proper composition. Besides affording this information which speaks both to the eyes and to the senses, and satisfies the mind the more fully because we are able to verify the results, there is another not less useful, viz., the determination of the natural resources of the fertilising agents contained in the soil as regards the principal produce of the locality. An experimental field of this importance would not only rouse the curiosity of the surrounding population, it would excite their energy, and lead them to make analogous trials for themselves, which would serve as a useful comparison between the experimental field of the district agricultural society or committee and those of private individuals. The small farmer would assuredly wish to see if his own experiments tallied with those of the local agricultural society, and the benefits that would arise from this exchange of information would result in its diffusion throughout the country amongst all classes of the community—amongst those devoted to science as well as the practical everyday workers—and doubtless much useful discussion would be thereby provoked.

*If I need quote an example in order to justify my insisting upon this point, an instance that occurred during the latter years of the Empire will furnish me with one. In 1869 M. Duruy, then Minister of Public Instruction, who had a passion for progress and the public good, conceived the happy idea of extending amongst the country children the ideas that I have endeavoured to make clear to you. He commissioned

me to put the plan into execution. Being persuaded that in order to make a good agriculturist, it is most essential to place before the child practical information on the causes and agents which regulate vegetable production by appealing to his senses, my plan was simple enough. I resolved to place the children face to face with three facts that would be impressed upon them. In the first place to prove to them practically, that with a very small quantity of a certain powder one was able to obtain finer harvests than with a large mass of farmyard manure. In the second place, that in this powder, which was composed of four substances, the suppression of only one (the dominant ingredient) would be sufficient to considerably reduce the good effects of the other three. It appeared manifest to me that if I got certain ideas rooted in the minds of these children considerable results would certainly have been obtained, because the children who had seen the chemical manure and the crops, even if they had only a faint idea of what was meant by calcic phosphate, potash, or nitrogenous matter, would retain a remembrance of the experiment. They would perceive that with something that was not farmyard manure, finer harvests were obtained than with farmyard manure itself; and further, that this fertilising powder consisted of substances possessing variable action according to the nature of the plants. Fancy an experimental field attached to a village school, where, with the aid of chemical manure, hemp has been grown 2 yards in height, while on the same ground unmanured the hemp was only 31½ inches high. What amount of teaching would produce so lasting an effect upon the minds of those children? But perhaps it will be said that this is pure hypothesis on my part, and that it is not certain that experimental fields would produce such results? The answer is easy, examine the tables and you will find the products of nine hundred experimental fields, classed in departments, which will also give you the results of the attempt made by M. Duruy.

These tables refer to two different kinds of crops, beetroot and potatoes. With 24 tons of farmyard manure, beetroot produced on an average 17 tons 12 cwts. per acre; with 9 cwts. 48 lbs. of chemical manure, the yield was increased to 19 tons 11 cwts., and this, when the soil without any kind of manure had only produced a yield of 9 tons 14 cwts. per acre.

This example surely does not need any commentary :—

	Per acre	
	Tons	Cwts.
With chemical manure . . .	19	11
„ farmyard manure . . .	17	14
Soil without any manure . . .	9	14
9 *		

We have been sufficiently ambitious to add other experiments to this last, which is founded upon the fact that of the four materials of which the chemical manure is composed there is a particular one, the suppression of which is sufficient to considerably reduce the good effects of the three others.

We have experimented with mineral manure without nitrogen, composed of calcic phosphate, potash and lime, and the crop only amounted to 13 tons 9 cwts. per acre. With nitrogenous matter alone the crop amounted to 15 tons 14 cwts., and by mixing nitrogenous and mineral matter we obtained a yield of 17 tons 12 cwts. per acre. We have, then, been enabled at three hundred and fifty different parts of France to put the following three results before some thousands of children: (1) that it is possible by means of chemical agents to obtain more abundant crops than by using ordinary farmyard manure; (2) that in using these substances it is necessary to follow the laws laid down by science; (3) that a very slight modification of the composition of the manure seriously detracts from their efficacy. With potatoes the results have not been less significant, though these tables were compiled at the latter end of the year, and after an exceptionally dry season. The number of fields in cultivation at the time was 564, with the following result:—

		Per acre	
		Tons	Cwts.
With farmyard manure . . .	.	6	4
„ chemical manure . . .	.	6	11½
Upon soil without manure . .	.	4	8

Is it possible to diffuse more useful notions than these throughout the country?

Do you believe that a child who has seen and followed such experiments, when he becomes a man and cultivates his own land—when he is struggling with the necessities of life, do you believe, I say, that the child will not remember, and that the seed you have planted in his young mind will bear no fruit?

You see by this example the part that it is possible for an experimental field to play, whether we desire to know the true state of the soil with a view to carrying on farming operations on a large scale, or simply to instruct the country labourer in the laws of vegetation and the practical conditions that are at the root of successful farming.

This method of teaching which has been in practice in primary schools, and which, had it not been for the events of 1870, would have become the basis of elementary agricultural instruction throughout the country, has also been adopted by

farming schools, and in all the establishments connected with the agricultural departments of the State.

The results have been the same as in the school experiments. We have in fact in 34 farming schools grown 15 tons 9 cwt. of beetroot with 19 tons of farmyard manure, 15 tons 12½ cwt. of roots with half a ton of chemical manure, whilst the soil without manure has yielded only 9 tons 13 cwt. At Grignon the same results were observable—beetroot with a large amount of farmyard manure producing 25 tons 5 cwt. of roots, and with the chemical manure 26 tons 1 cwt.

But the method which I have just demonstrated, the application of which is so simple, is capable of solving certain problems in a very unexpected manner; for instance, it enables us to judge the state of the soil at a distance. Here is an example. In England analogous experiments to those which are being carried on at Vincennes are being conducted upon a large scale, and in this field Messrs. Lawes and Gilbert have attained a justly-merited reputation. The results obtained by those gentlemen and those we have obtained in France are alike in many respects, but differ in others. With the normal manure the yields are the same at Rothamsted and at Vincennes.

The soil at Vincennes is improved by mineral manure, whilst that of Rothamsted reaps most benefit from the nitrogenous matter.

The conclusion to be drawn from this comparison is that the soil at Rothamsted contained more mineral matter than that of Vincennes, whilst the latter was originally better furnished with nitrogenous matter. I say originally, because it is now in much the same state as that of Rothamsted. By comparing the results obtained with the same manures, we are enabled at the same time to define the analogies and differences which exist between the two soils.

I recently stated that within the confines of pure science this mode of investigation permitted us to arrive at conclusions which it would be impossible to obtain by any other means. If I were to affirm, or, better still, to prove to you, that when the earth was still young, the air of which our atmosphere is composed had not the same composition which it has at present, but that in the remote ages it contained more carbonic acid than it now possesses, besides a large proportion of ammonia, you would naturally find this a somewhat rash assertion, and you would hasten to become acquainted with the data upon which a similar demonstration could be founded.

You know that coal has for its origin vegetable growths of the early ages, and that such plants belonged to the great family of vascular cryptogams. These plants, as we know by their fossil remains, presented two characteristics in their organisation—the leaves were of colossal dimensions—the roots conical and disproportionately small. This contrast between two systems of equally important organs indicated that the plants took most of their nourishment from the air and very little from the soil, at the same time growing to a large size. The plants of the present age in which the organisation of lepidodendrons and calamites is reproduced belong to the lowest class, and consist chiefly of mares' tails and club mosses which rarely exceed 3 or 4 feet in height. For such a change to have taken place in the dimensions of these plants, a corresponding change must have taken place in the media in which they lived, seeing that the conditions under which the calamites and lepidodendrons increased and multiplied are not the same as those which govern the growth of mares' tails and club mosses in the present age. What, then, are these conditions? First we must have an atmosphere charged with carbonic acid and ammonia. As an experiment, take a large-leaved plant, for instance a caladium, which in order to render the demonstration more complete should be grown in calcined sand; place, I say, such a plant in a similar atmosphere, and you will find that it will suddenly attain an enormous development—the leaves will become more than 2 yards in length; the activity of development will surpass all those plant growths by which you are surrounded, and you will be almost inclined to believe that you are present at the resurrection of a bygone world.

Well, from a similitude in effect, you are justified in concluding there is identity of cause. In the first epochs of the world the soil was formed of mineral elements; there was no detritus of any kind such as we now have. Now, as it is possible in such a soil for vegetation to become extremely active by the absorption of a small quantity of ammonia contained in the atmosphere, it follows that the atmosphere in the early ages contained a nitrogenous compound which has since disappeared; but this is not all, for the last fifty years a timid feeling—more intuitive than reasonable—has sprung up in the minds of men, and has now become an openly asserted doctrine, which leads us to connect the aptitudes of nations and the vicissitudes they have undergone with the material conditions under which they have lived.

I select the following from among the results obtained :—

1. The primitive soils are decidedly unfavourable to the advance of life and the expansion of the moral and intellectual faculties. The races existing upon these lands have degenerated mainly because the climate is excessively warm and moist, and of its unfavourable influence on the soil.

2. The land formed in the midst of the waters during the diluvial period possessed a marked superiority over the preceding.

3. The most favourable conditions of existence are those alluvial soils of recent formation, the alluvial deposits of the present period¹

To these facts the observations of historians adds some others, for instance, the regions where human intelligence has attained its most complete development are those which are comprised between the zones, where cereals are cultivated—and amongst the cereals one is able to make yet another distinction, viz., between wheat, barley and rye—the effects being reproduced upon the population. These observations which throw a new light upon history will only be susceptible of a practical and positive application when we shall be able to put them into more precise terms. The experimental fields, thanks to the certain indications that they afford of the richness or poverty of the soil—enable us to fill up this gap.

In the department of Aveyron half the soil is composed of schist gneiss and mica-schist, the other half, which is alike in many respects, is composed of jurassic earth. The physiognomy of the two countries is entirely opposed. We will call the first ryeland, consisting of the rye-producing districts, and the second chalkland, from the composition of the soil.

The inhabitants of the ryeland or rye-eaters are puny, thin, angular, small in stature, and ugly rather than good-looking—their domestic animals resembling them in most of these points.

The inhabitants of chalkland, who dwell upon a chalky soil, are well built, tall, and handsome rather than ugly. The domestic animals participate in the contrast; those raised in the rye-growing country become fat when transferred to the chalky soil. Submit the soil of these two localities to chemical analysis with the view of ascertaining how it is possible to ameliorate their condition, and you will fail to obtain a satisfactory reply. Then have recourse to some modest experimental plots, and you will find that the soil in ryeland is wanting in nitrogen and phosphates, while that in

¹Trémeaux, *On the Origin and Transformation of Man*, 1865.

chalkland is deficient in nitrogenous matter and potash. Hasten, then, to carry out this teaching. Dress your land with nitrogenous matter, phosphates, potash and lime, and it will soon become evident that the growth of the rye is restricted, while that of barley is increased, and after a time wheat will succeed the barley. When we use nothing else but farmyard manure effects like this are impossible, the manure always retains the indelible mark of its origin; if the soil which has produced it is deficient in phosphates, the same will naturally be the case with the manure. A rye-producing soil will always remain a rye-producing soil—the man who inhabits such a locality is of stunted growth, his existence and his faculties are submitted to the thralldom of a power which weighs him down, embraces and enslaves him, the effects of which he is unable to withstand.¹ By the light of science such bondage ceases to exist. Once master of the conditions which influence the life of plants, man can, although not without effort, change the plan which oppresses him and alter the course of his destiny by modifying the organisation of the animals and plants which are the source of his nourishment. To soil lacking in phosphates and nitrates let him add phosphates and nitrogenous matter, and instead of living upon rye bread he will be able to live upon wheaten bread. By this substitution he will, after two, three or four generations, rise one degree in the biological scale; his organisation will become perfect, and his mental faculties will be extended. Such a conquest over the native inferiority of his race will be entirely due to the inductions of science and to his own voluntarily excited energy and perseverance. You see, then, that when we lift a corner of the veil that still hides from us the laws that regulate the advance of life, we feel dazzled; between man and creation there was formerly an impassable barrier, but now we feel intuitively that we may boldly affirm that this barrier no longer subsists.

By discovering the secret springs which regulate human life, man has made himself its master, as he has of steam and electricity, which he uses as his wind and his thunder. By this knowledge he can control his own conditions of existence, and by more effectually balancing them he gives greater depth, unity and prominence to those analogies of nature which produce in the midst of a nation that fusion of thought and feeling expressed by the magic words, OUR COUNTRY.

¹ The rye-consuming populations of Westphalia, Pomerania and other parts of Germany are certainly not stunted in growth.

If the productive forces of the soil are increased the conditions of life are ameliorated, and the population is increased in proportion. If the law of restitution be infringed and the soil weakened, an inverse effect is produced, the population retrogrades, and death becomes more powerful than life.

I promised you a practical lecture, but it appears that I have somewhat neglected this pledge. We will go back, then, and I will with your permission tell you what will be the subject of our observations when we proceed to the experimental field.

The night of, or the night before, my first lecture a storm had laid the wheat, and the cold of the preceding month had arrested the growth of the maize and also of the beetroot. A fortnight has hardly elapsed since these accidents, but fine weather has set in, warmth has returned, the sun and the chemical manure have both done their work. We will go and examine in detail, and discuss step by step the evidence placed before us at the present time by the experimental field. The first question that I wish you to understand is this: that with the four fundamental constituents of which I have spoken the maximum yield can be obtained, and that by varying the proportion of nitrogenous matter for wheat, beetroot and swedes, we graduate the crops, whilst the nitrogenous matter, which here is so efficacious, does not act beneficially upon peas, the predominant action being in their case most effectively produced by potash. In order to gain the greatest possible amount of good from an experimental field, it is necessary that you should frequently visit it at different periods of the year, and follow its progress from the germination of the seed till the crops are ripe. Unfortunately the short duration of our lectures will not permit of our going deeply into the subject. I must endeavour to obviate this by showing you a multiplicity of crops, some of which are commencing while the others are finishing. Thus, side by side with wheat, the ear of which is fully formed, you will find a crop of hemp just peeping above the ground, and another of maize a little more advanced.

Passing from the one to the other, we shall first show the efficacy of chemical manures upon all these plants; then the inequalities that arise by the suppression of this or that element; and so to place clearly before your eyes as much as it is permitted us to know with respect to the reasonable and judicious application of the theory of dominant constituents.

LECTURE X.

WHAT IS GAINED BY FARMING WITH FARMYARD MANURE ONLY.

THE three last lectures have produced the following results :—

The first showed us that the fundamental data on which the doctrine of chemical manure rests are justified by the practice of the past.

The second made us acquainted with the agents which take part in plant life, and the conditions which determine their activity.

The third showed how the soil may be analysed, by taking as a basis the testimony of the plants themselves. In the present lecture we shall view our subject under a new aspect, which will lead us to the very root of the agricultural question.

We will first inquire what is produced and what is gained by adhering to the use of farmyard manure only, as was the custom in ancient times.

In the cultivation of the land there are two orders of questions which must not be confounded: (1) The yield of the crops, or the total amount of the products obtained; (2) the profit resulting from the working.

The first of these is a question of social, and the second of private, interest. Let us endeavour to define them both.

The aim of agriculture, viewed in the light of social interests, is to feed the people at the lowest possible cost. It is therefore a matter of importance to them whether large or small crops are obtained. The agricultural system most satisfactory to the community is that which brings most provisions into the market and produces the greatest quantity of meat, corn and vegetables per acre, thereby feeding the largest number of individuals.

But the farmer looks at the matter from quite another point of view; he has devoted his time, his trouble, and his capital to his farm, and from his point of view the best system of agriculture is that which produces the largest profit; the interests of the community are respected by him only so far

as they coincide with his own. And who can blame him? Let us take two systems of rotation for instance. In the one the fields are allowed to lie fallow from time to time, in the other they are always under cultivation. The profit on being calculated, in spite of the smallness of the crop, is found to be much larger in the first case than in the second. Do you think, therefore, that the farmer would be likely to choose the second system? He certainly would not, and you can hardly blame him. But on this account it frequently happens that an antagonism exists between the interests of the community and those of the producer. The latter is naturally anxious for profit, whilst the consumers, on the contrary, demand the largest possible supply of food at the smallest possible cost.

There are, then, two sides to the agricultural problem, which, although not necessarily antagonistic in their nature, may under certain conditions become so. These two sides must be taken into consideration if we would rightly estimate the agricultural state of a country and the system of cultivation upon which it is based.

We will therefore first consider the question from the social point of view, and inquire what is the amount produced under the system in which nothing but farmyard manure is used, and in what measure it satisfies the primordial requirements of the people—"life at the lowest cost".

Taking France as an example, the answer to this question is lamentable and distressing, for the average production of wheat for the whole of France is only $14\frac{1}{4}$ bushels per acre. It is true that out of the whole of the departments there are 29 or 30, those of the Nord especially, where the average yield of wheat reaches 21 bushels. In 13 departments the yield is $15\frac{1}{2}$ bushels, but in 46 others it averages only $13\frac{1}{4}$. In other words, France, under the system by which farmyard manure only is used, produces on an average not more than $14\frac{1}{4}$ bushels per acre.¹ It is not necessary to be very deeply versed in economic science to see the danger of this state of affairs.

In 48 departments the population is increasing, in others it is stationary, whilst in 39 it is decreasing year by year. Now, if it be true that there is a connection between the increase of a population and the conditions of existence dealt out to it, and if the prosperity of a country may be measured by the rapidity of this increase, which is regulated by the amount of food produced in that country, it is certain that

¹ These figures for the 89 departments show an average of 16 bushels instead of $14\frac{1}{4}$ bushels.

the state of France would now be very different if the system of farming which I am advocating had been long since adopted. If instead of a population of only 38 millions we could have boasted of 45 or 50 millions, the recent struggle would have had a very different result.

A long time ago I called the attention not only of the public, but of the most influential representatives of the political world to this fact.

In 1846 the births exceeded the deaths by 200,000 in a population of 35 millions, whilst at the present time, with a population of 38 millions, they are only 120,000 in excess of the deaths. According to this calculation it will take our country 140 or 150 years to double her population, while Germany doubles hers in 60 years, and England in 50.

An attempt is made to extenuate this state of things, by calling attention to the wealth of the country which could sustain, without sinking, the weight of a formidable debt, such as that imposed by the Germans after the late war.

It is true that our financial resources are great, because Providence has endowed us with a privileged climate, and because no nation practises thrift to a greater degree than we do, but very different is the situation of a people amongst whom the spirit of forethought arrests the increase of the population, from that of a people whose faith in the future leads them to private enterprise, by which means they raise the production to meet the requirements of an increasing population. Do you think that he who amasses wealth at the cost of privations will be the equal of him who amasses it by dint of superior activity? And is it not certain that he whose physical, moral and intellectual faculties attain their full development is superior to him whose faculties, obliterated by covetousness, are restricted and wasted under the fetters of an exaggerated and almost criminal care for the future?

From the point of view of general interests, notwithstanding our excessive luxury and our immense imports, I have no hesitation, in the face of our retrograding population, in declaring our agricultural situation to be lamentable, and threatening in the highest degree.

Is private interest, however, better divided? Is much profit gained by cultivating with farmyard manure, according to the rules of the past? Are fortunes rapidly made? The answer to this will be found in the words of the celebrated Lavoisier, one of the great men of whom France has reason to be proud. Lavoisier was not only the first chemist of his time, but he possessed in a high degree the ruling faculties of a statesman. Farmer-General at a time when

France had financiers, he displayed, in the exercise of his office, the greatest administrative ability. His treatise on the territorial wealth of France, which was printed at the expense of the State, is a manifest proof of this.

Led by the nature of his work to make inquiries into agricultural questions, Lavoisier determined to make himself fully acquainted with the subject, and to this end he became farmer himself.

He bought a farm of about 200 acres between Blois and Vendôme, took shares in various farms, and also, in the financial sense of the word, farmed a large portion of the tithes of the district, so that he interested himself in almost all the farming operations of the country. After eight years occupied in experiments, calculations and researches, what conclusion did Lavoisier arrive at? I will give the answer in his own words.

“After eight years of farming I obtained a considerable increase in fodder for cattle, abundance of straw and farmyard manure, but *little interest for the money expended*.

“Progress in agriculture is excessively slow, but what I have discovered with pain and learnt to my cost is that *whatever attention or economy may be practised, it is not possible to obtain more than 5 per cent. on the capital advanced*.

“Unless our attention has been called to this subject, and we have closely followed farming operations, nothing seems more easy than to revive a system of agriculture which has fallen into a state of decline, and persuade ourselves that cattle and money only are necessary for it. But when we pass from theory to practice the result which we must arrive at is, that the proprietor, at any rate under the conditions in which I am placed, takes away only between one-third and one-fourth of the crop, while the duties and taxes swallow up almost as much more—the remainder, less than a third, is all that remains to the farmer for his labour, food, expenses of working, reimbursement of the interest of his capital, and all incidental expenses.

“Still the most distressing part of the picture is that with a languishing system of cultivation, such as prevails for the most part throughout France, there remains at the end of the year almost nothing for the farmer, who esteems himself happy when he is able to drag on a miserable and wretched life; and if by the strictest economy he is able to save something during profitable years, that little is soon absorbed during average and bad seasons.”¹

In short, Lavoisier, who worked with all the resources

¹ Lavoisier, *Grand National edition*, vol. ii., p. 312.

given by a large fortune, who possessed orderly habits and knowledge that made him one of the greatest masters in the art of applying scientific methods, brings us to the conclusion that a large amount of money is necessary in order to attain a poor result, that the agriculturist loses, and the capitalist is not able to get 5 per cent. for his money advanced. But you will tell me, this sombre picture belongs to a state of things now far removed from us. To-day it is no longer the case. At the present time we gain a great deal, and agricultural profits equal those of trade. I will cite for your benefit a few of the most recent examples, and certainly they are very decisive in their teaching. I will take as my second example Mathieu de Dombasle. You know the history of this good man, who, in the full maturity of age, became inspired with ideas to which he was devoted, and for which he sacrificed himself. An old student of the "Ecole Polytechnique," Mathieu de Dombasle was one of the first who manufactured sugar from beetroot. In 1823 he met with a reverse of fortune, just as he had commenced to cultivate clover and grass upon a large scale. Exaggerating the importance of the advantages that would accrue at a time when only uncertain and vague notions were held respecting the agents of plant nutrition, Mathieu de Dombasle resolved to show, by an example which the most humble could imitate, that by the help of a small capital it was possible in a short space of time to improve the worst soils, and to raise the crops to a level with the best. Persuaded that alternation of crops was a powerful means of amelioration, he wished to furnish an indisputable practical demonstration of the fact. Having the welfare of the country in view, he, a man of the world, became a simple farmer working with a small capital, a third part of which he borrowed, thus placing himself voluntarily in the position of most of our farmers in order to give greater emphasis to his example.

He then took the lease of the farm of Roville, which a grateful public has since termed the Institute of Roville, and there for ten years he did all that earnest devotion, application, carefulness and a skilful knowledge of farming economy were able to realise.

And what was the result of his efforts? Taking first the results of cultivation, the yields were as follows:—

	Yield per acre
Wheat	15½ bushels
Colza	12½ „
Beetroot	7 tons
Hay	1 ton 5 cwt.

With such crops it is easy to foretell the financial result, but I will quote the balance of profit for these same crops :—

	Outlay			Produce		
	£	s.	d.	£	s.	d.
Wheat	4	14	0	4	18	4
Colza	4	0	11	4	1	7
Beetroot	4	16	9	6	2	6
Hay	2	16	9	2	5	0

Upon the beetroot alone is there a decent profit, and the exception is due to the fact that there was a distillery at Roville at which 1*l.* per 880 lbs. of roots was paid—an inferior price to the ordinary commercial tariff. With a fidelity that does him credit, Mathieu de Dombasle has left us the complete account of the first nine years of his administration, from 1824 to 1832. The following is a *résumé* of the result :—

	£	s.	d.
Expenditure	1,714	8	1
Receipts	561	4	5
Net loss	£1,153	3	8 ¹

With precarious yields there is an inevitable loss! Roville possessed a manufactory of agricultural implements, which during the same period produced a profit of 1,600*l.*, which raised the profit of the establishment to a sum of 475*l.*: a

¹ Extract from the accounts of the results of farming at Roville during the first ten years :—

Annals of Roville, vol. viii., p. 37.

Dates of balance sheet	PROFIT AND LOSS								
	The two establishments				The farm				
	Profit		Loss		Profit		Loss		
	£	s.	d.	£	s.	d.	£	s.	d.
1824	—			495	16	6	—	469	6 2
1825	340	2	2	—			230	17 5	—
1826	115	4	9	—			—	77	15 4
1827	48	12	9	—			—	36	16 4
1828	—			283	6	4	—	283	17 9
1829	516	8	8	—			295	7 3	—
1830	380	18	0	—			34	19 9	—
1831	—			76	17	5	—	474	13 8
1832	—			69	14	5	—	371	18 10
	1,401	6	4	925	14	8	561	4	5
	Profit £475 11 8				Loss £1,153 3 8				

lucky result, but which had nothing to do with the farming operations carried on during the same period, which resulted, I repeat, in a loss of 1,153*l*.

But if Mathieu de Dombasle did not succeed, what can we think of those presumptuous persons who pretend to do so by following the same errors, by working only with cattle and farmyard manure? You may say the available funds were too low at Roville. I grant it. But to those who contend that by raising the available expenditure from 4*l*. per acre, as it was at Roville, to 8*l*. or even 16*l*. per acre, the yield by farmyard manure alone would become remunerative to these enthusiasts, I will quote the case of Grignon as an example, and invite them to think over it.

Grignon was founded in 1828, with the idea of demonstrating that culture by farmyard manure alone, when backed by a capital of 16*l*. per acre, would at the same time realise maximum crops and maximum profits. In the absence of sufficient documents I need not go into the financial results obtained at Grignon by M. Bella, sen., its estimable founder. My argument shall be carried on indirectly, but the results will be none the less plain, precise and conclusive. I will first remind you that Grignon was in an exceptional position. The farm paid no rent; the land of which it was composed—consisting of 750 acres—had been leased for 40 years, during which time the farmer was expected to expend 12,000*l*. in improvements, of which he was the first to reap the profit, and which he had time to pay off. This is one condition of which you will readily perceive the advantage. When I first stated that Grignon had not furnished the demonstration promised by its founder, that is to say, that by the use of farmyard manure alone high farming of every sort could be carried on successfully, I raised a veritable tempest; yet nothing is more true, as will presently be seen. Let us make an abstract of the financial results, and then ask ourselves what has been the increase in the production at Grignon under the management of its founder. The rotation of crops carried on at Grignon lasted for seven years, which is a long time. The first year the following results were obtained:—

	Per acre
Wheat	23 bushels
Spring wheat	24½ „
Colza	24½ „
Oats	43 „

For the seventh year:—

	Per acre
Wheat	26½ bushels
Spring wheat	28½ „
Colza	17½ „
Oats	65 „

Whilst with the oats the improvement is such as to yield an increase of 22 bushels per acre, we find a decrease in the yield of colza and an increase of 3½ *bushels with the wheat*, that is to say, 16l. of capital per acre was sunk to obtain an increase of 3½ bushels of grain per acre after seven years' labour.

If I wished to invert the order of your studies, I could immediately prove to you that with chemical manure to the value of 2l. 8s. or 2l. 17s. 7d. per acre we should arrive at a far better result, producing easily a yield of from 27½ to 33 bushels per acre, without risking the fluctuations of chance to which large capital is always exposed.

If Grignon had been worked under the ordinary conditions, and had been obliged to pay an annual rent, it would have ended like Roville; and the best proof that Grignon deserted its flag, and was untrue to its creed, is that during the last years of Bella's experiment from 600l. to 800l. worth of manure was annually purchased from other places. Observe the terms of our argument. Must farmyard manure be proscribed? Certainly not. Neither must its production be made the pivot on which farming turns. No. What, then, is the rule? It is always to use large quantities of farmyard manure, but to regulate the proportion used according to its cost. If it is dear use little, if it is cheap use much; but, little or much, employ other fertilising agents, such as ammonia, nitrates and phosphates, in order to always obtain the maximum results. It may perhaps be again said, "But what has failed at Roville and Grignon may possibly succeed elsewhere"—in other words, you will ask me for additional proofs. It is easy for me to furnish them. M. Boussingault, a singularly learned, sagacious and prudent man, has published the results obtained on a farm at Alsace, which was managed on the system of using farmyard manure exclusively. The estate is composed of 275 acres, of which 150 are grass land—this is the proportion traditionally accepted: it is impossible to do better when working with farmyard manure only; but what were the yields?

Wheat	20 bushels
Oats	35½ „
Beetroot	10 tons 8 cwts.
Hay	1 ton 6¼ cwts.

It is assuredly not science that failed at Bechelbronn, yet, as at Roville, only precarious crops were obtained. The balance-sheet is just as unsatisfactory, for after all expenses were paid the profit was 131*l.* 18*s.* 7*d.*, the ground rent being reckoned at 3 per cent. Here are some of the items of this gloomy account :—

<i>Receipts.</i>				£	s.	d.
Vegetable products	.	.	.	818	8	0
Animal	„	.	.	518	8	9
				£1,336	16	9
<i>Expenditure.</i>						
Rent of farm	.	.	.	396	8	0
Labourers' wages	.	.	.	220	11	2
Stable expenses	.	.	.	666	11	2
				£1,283	10	4

It must also be remembered that in the expenses we do not find the manager's salary. Is this, then, a financial result which would enable us to consider the system a profitable one? The more I multiply my examples, the more my conclusions are confirmed. I will, however, quote yet another example, which appears to me to carry more weight than the preceding ones. At the time of the grand agricultural inquiry in 1866 the Cambrai Chamber of Agriculture resolved to settle the question by means of a farm of 250 acres, which was to become the model farm for one of the departments of the North. What was the result? That a farm of 250 acres with 3,200*l.* capital, of which 1,600*l.* was used for buildings and stocking the farm, and 1,600*l.* invested in working expenses, brought in an annual profit of only 126*l.*, notwithstanding that the farmer charges nothing for his management.

Lavoisier, Dombasle, Bella, Boussingault lead us to the same conclusion as the most eminent practical men, giving us spontaneous, and altogether disinterested, testimony. You may say perhaps that these results can be improved by the annexation of a distillery or a starch factory, and that by adopting these means a farm can always be made to pay? We must, however, remember in the first place that this course is impracticable to all but a select few, for the cost of establishing a distillery cannot possibly be less than 8*l.* per acre. One of our most eminent civil engineers who has established a large farm in Normandy, and who this year contested for the first prize, fixed the cost of material, without counting either the buildings or the working expenses, at 8*l.* 10*s.* per acre.

But is it certain that by the addition of a distillery we can raise the value of the crops in a short time and realise a handsome profit? M. Houel, the engineer of whom I have just been speaking, obtained at the end of ten years, with great difficulty, from 24,640 to 26,400 lbs. of beetroot per acre, and also realised from 3 to 4 per cent. upon the capital laid out, and this in spite of the powerful and various means he employed.

Capital Invested.

	Per acre		
	£	s.	d.
Purchase of farm	28	12	0
Building and roads	28	10	1
Lime for dressing	2	16	0
Drainage	1	9	2
Improvements	10	8	3
	<hr/>		
	£71	15	6

Agricultural and Industrial Capital.

	Per acre		
	£	s.	d.
Cattle	0	17	5
Agricultural implements	4	6	4
Household and office furniture	0	13	4
Plant for distillery	8	10	0
Working capital	12	18	10
	<hr/>		
	£27	5	11

71*l.* 15*s.* 6*d.* on the one hand and 27*l.* 5*s.* 11*d.* on the other makes a total outlay of 99*l.* 1*s.* 5*d.* per acre, being three times the price of the original cost; and in order to obtain what?—26,400 lbs. of beetroot per acre, and an interest of 3 per cent. But would a simple farmer of 100, 125 or 250 acres be able to do this? In the first place, in order to make a distillery successful, it must be conducted on a large scale. If the farm itself is not able to supply the demand, it becomes a mere accessory, and I ask if such an arrangement can be called a solution of an agricultural question?

What, then, do we learn from the example of M. Houel? That farming with farmyard manure is slow in its effects, and singularly onerous in the means it employs. It is not the man, not even his example that I criticise—it is the system. In farming with farmyard manure, then, there is one radical vice: the slow action and insufficiency of the real fertilising agents which the soil is able to furnish.

What, then, is to be done if abundant crops are desired with the least possible delay? The farmer must apply plenty of manure, and, if he has not enough, he is forced to buy and

give up producing it. The result will be that the manure-heap will ultimately become an accessory merely. The great producer of manures will be the manufacturing chemist, and instead of producing it at any cost by turning half of the farm into grass land, each one will regulate his system of farming by the crops which he is best able to dispose of. One distinct locality will be for cattle grazing—which will be the lot of Normandy, Cotentin and similar districts; another in our central departments for wheat, leaving the South for the vine, oil, fruits and early vegetables. Above all, farmyard manure will become the accessory even in the districts devoted to pasturage, for there especially the principle of high farming by chemical manures ought to be applied. Everything calls for it: the burdens which overwhelm us and which it is necessary to reduce; our population, which is decreasing, and which must be reinvigorated; a too restricted exportation to which we must give an impetus in order to benefit our mercantile marine service, which in return would give us economical means of transport for those raw materials which we do not produce but which are needed for our manufactures.

To make the necessity of importing manures instead of producing them at any cost as plain as a mathematical demonstration, I give the following table, in which I have given the cost of everything necessary for the production of an acre of wheat:—

		£	s.	d.	£	s.	d.
Fixed charges	{ Rent	0	14	5	2	19	9
	{ General expenses	0	16	10			
	{ Cost of labour	0	13	10			
	{ Seed	0	14	8			
Variable charges	{ Manure	1	3	8	1	14	4
	{ Harvesting and thrashing	0	10	8			
					<hr/>		
Subtracting value of straw					£4	14	1
					0	16	0
					<hr/>		
Net cost					£3	18	1

Let us analyse the items of this calculation. Under the head of culture there are expenses of two kinds: fixed expenses which do not change, and variable expenses. The fixed charges include rent of ground, cost of culture, labour, tilling, seed and general expenses. At the Institute of Roville the whole of these charges amounted to 2*l.* 18*s.* 6*d.* per acre.

Under the second heading come the variable charges represented by the manure, and the cost of harvesting amounting to 1*l.* 14*s.* 4*d.*, giving a total of 4*l.* 14*s.*, from which, however, it is necessary to deduct 16*s.* for the value

of the straw. The total expenditure to produce 15 bushels of wheat is then 3*l.* 18*s.* 1*d.* This makes the cost of 1 bushel 5*s.* 2½*d.* Now if, without in any way changing the organisation of the estate, without extending the buildings, without improving the implements, without increasing the live stock, without adding to the chances of loss, we simply purchase 1*l.* 18*s.* 4*d.* worth of chemical manure per acre per annum, the account would stand as follows :—

		£	s.	d.	£	s.	d.
Fixed charges, as before	.	.	.	.	2	19	9
Variable charges, which are	{ Manure .	3	2	0	4	1	2
	{ Harvesting .	0	19	2			
Total cost					7	0	11
Deduct value of straw					1	10	4
Net cost					£5	10	7

The charges are increased from 3*l.* 18*s.* 1*d.* to 5*l.* 10*s.* 7*d.*, it is true; but the crop has increased in proportion. Instead of 15½ bushels it is raised to 31 bushels, which brings down the cost of 1 bushel of wheat from 5*s.* 2½*d.* to 3*s.* 6½*d.*

With an increase of manure, costing about 1*l.* 18*s.* 4*d.*, we should be able to obtain an increase of 15½ bushels in the crop. Everything else remains in its primitive state, farm buildings and cattle and personal effects, excepting that the cattle will be better provided with straw, and the yield of hay will be increased; we shall be able to restrict the ground devoted to grass, and introduce certain crops of an industrial kind with great profit. The farmer should never cultivate with a small amount of manure, for manure is the first principle of agriculture. When he cultivates with little manure he places himself in the position of a manufacturer, who, having founded a manufactory at great cost, feeds it with only half the proper quantity of raw material. Provided with the most perfect apparatus, each portion used in the work gives only half of what it is able to give, and therefore the general expenses are doubled. For the agriculturist the plant is the most important organ of production, the soil is the bed on which the plant rests, and the manure is the raw material. With little manure small results only are obtained, and the general expense absorbs the profit. With plenty of manure good results follow, and the general expenses are diminished by reason of the increase of the products.

By the importation of manure we obtain large yields, certain profits, abundant crops, good food at a cheap rate;

for society, security ; for the producer, success and fortune ; and harmony and concord between all classes, by reason of the progress made. What becomes, then, of the ancient formula, grass land, cattle, cereals ? The expression of what at one time was considered great progress and retained as a sound legacy, is to-day regarded only as the remains of a lifeless monumental fossil. But here an objection arises which, were it not refuted, would be capable of destroying the new edifice.

If everybody practised the high-farming system, would not the markets become glutted and prices lowered ? Would not profits disappear and universal misery reign in the midst of abundance ? Egypt, for example, yields two crops to our one, yet the population after ten centuries is more backward than those of the most unenlightened provinces of Spain and Portugal.

Such a danger need not be feared. It is one of the marvels of the new solution, that a simple displacement in the profit of production suffices to restore the equilibrium between the supply and the demand, the resources and the needs, production and consumption. What would cause this ? A few more cattle, a little less wheat, and the replacement of inferior cereals, such as rye or barley, by wheat. The smallest change in the proportion of these three products is sufficient to restore the equilibrium in cases of excess. For example, on an equal area of soil potatoes produce four times more food than wheat, and sixteen times more than grass, which is afterwards converted into meat. Here, then, is an excess of potatoes and of wheat, but a very slight impetus given to the production of meat (grazing) suffices to restore the equilibrium.

The food supply is improved for the generality of consumers, and thanks to the improvement the active working-man accomplishes more useful labour, and consequently draws an overplus of salary. Everything in a country depends on, and all prosperity arises from, the abundance and the quality of agricultural products. Take, in the first place, the vigour of the population, compare the work of a Calabrian peasant with that of a Belgian navvy, and the contrast seems inexplicable ; but take into consideration the diet of the two, and the explanation is at once apparent. We will notice generally the products of the soil in Belgium and in Calabria, and base our statistics on the crops produced. In Calabria the food supply consists of fruits and leguminous plants ; the analogous products in Belgium are converted into meat, which with wheaten bread, beer and

coffee forms the staple diet of the working-man. The method of high farming can be extended and generalised without risk, new methods would become capable of being extended and generalised without peril. There will never be overstocked markets, nor a lasting lowering of price. There will be transitory crises; but in the end there will be improvement in the general food supply, and consequently improvement and progress in the physical organisation of the people, in their power of labour, in their aptitude and in their intellectual and moral faculties.

This is how the agricultural question ought to be considered, how the problem ought to be stated, and how it ought to be solved. We may again sum up the whole principle in four words. Use plenty of manure! Cultivation by means of farmyard manure is not equal either to the necessities of the present day or to the exigencies of our social condition. It is not remunerative to the farmer; to society it gives no security. Who will pretend to do better than Lavoisier, and to succeed where Mathieu de Dombasle, Bella and Boussingault failed? To pretend to do this would be the height of presumption, and to attempt it an act of great folly. If you wish your farming to be remunerative never say, "I am going to produce manure"; say, "I am going to manure in larger quantities". If you lack farmyard manure, buy other kinds, bring it in from outside. Having within your reach a simple practical method of discovering what the soil lacks, the choice of fertilising agents has nothing arbitrary or adventitious about it: it is on the testimony of the plants themselves that the selection is made. In any case the production of farmyard manure is not the starting-point: it is only a subordinate element in the solution of the agricultural problem. The judicious and reasonable starting-point, the true condition of success, is to give the ground such manure as is necessary in order to obtain the maximum crops. There is the source of profit and the assurance against disappointment.

With farmyard manure alone no distinction is possible between manure containing substances with which the plants are well supplied, and those they do not require, whilst those they need are often withheld. If we analyse the excreta of a sheep bred on the sandy moors in Gascony, we shall find only insignificant traces of phosphates; examine the skeleton, there is, properly speaking, no bony framework, but only hardened and gritty tendons. How can cereals be obtained with such manure? But by the introduction of chemical manure the whole system of farming becomes

simple, just, economical and harmonious, each plant receiving what it requires.

The question of principle being settled, let us pass on to the rule which it is necessary to follow in its application. The rules are very simple: give manure to the value of 1*l.* 18*s.* 4*d.* to each acre of all your crops; and as grass land is included in the list we must either increase the number of cattle or reduce the grass and make room for what may be called industrial crops, such as hops, tobacco, hemp or colza, which must be well manured. At Bechelbronn, for instance, with farmyard manure alone little was produced, and the gain was only 133*l.* 6*s.* 5*d.*; but under the new system, by the introduction of 240*l.* worth of chemical manure, half as much again was produced, and the gain was between 400*l.* and 480*l.* instead of 133*l.*

In order to gain the 133*l.* odd it was necessary to have a working capital of 1,400*l.* By raising it to 1,640*l.* the annual profit increases, as I said before, to between 400*l.* and 480*l.*; and it will be observed that this 240*l.* which represents an increase of expenditure is not lying dead; it is, on the contrary, redeemed the same year.

What can be more simple, more rational and altogether more satisfactory? The results in the case of grass land are equally certain, as will be seen from the following statement on this subject by a well-known farmer of Calvados, M. Ad. Welbien, who has treated his meadow land with chemical manure. I will quote literally: "I was waiting to thank you for your advice till I had confirmed by experience the merit of your last formula for manure. The success is most complete. I obtained a quantity of grass which grew to the height of about 4 feet. In one piece of 12½ acres (not the very best quality, and only grass of the second year) I put 28 oxen, which have been well fed for the last three weeks, and have not yet consumed the whole of the grass and clover. I spread some chemical manure over 50 acres of meadow, and everywhere a luxuriant crop of grass is fattening my cattle. I have 61 head of horned cattle on the property, of which 40 are oxen, and I should be able to feed double that number with my superabundant grass. I hope that after using your new formula for two more years I shall be able to raise the productive power of my land to the level of the best pasturage in the country, by combining the action of the chemical manure with that of the cattle kept on the place, the number of which I shall increase. The farm consists of 87½ acres of land, all laid down in grass, of which 50 acres have been treated with chemical manure. I observe

that cattle prefer the grass manured with your formula, and that they fatten better on it. This is very probably due to the presence of potassic chloride in the grass, a salt which may be considered a substitute for sodic chloride or common salt, of which they are so fond. I am at this time mowing a meadow, the grass of which is very remarkable; it falls in heaps under the scythe, and the mowers, who do not conceal their surprise, tell me that there is two or three times as much as in a good crop of excellent meadow land."

As a last argument I appeal to the balance-sheet of a farm of 250 acres, drawn up by the Cambrai Chamber of Agriculture. The figures speak for themselves:—

Annual Charges on a Farm of 250 acres.

	£	s.	d.
Interest at 5 per cent. on 2,400 <i>l.</i> , being the purchase-money at 9 <i>l.</i> 12 <i>s.</i> per acre	120	0	0
Repairs and current expenses	40	0	0
Plant and implements, at 6 <i>l.</i> 8 <i>s.</i> per acre = 1,600 <i>l.</i> , at 5 per cent.	80	0	0
Working expenses, at 6 <i>l.</i> 8 <i>s.</i> per acre = 1,600 <i>l.</i> , at 5 per cent.	80	0	0
Ground rent, second class, at 2 <i>l.</i> per acre	500	0	0
Commission on ground rent, 1 <i>s.</i> 9 <i>d.</i>	55	11	2
Rates and taxes	60	0	0
Farm overseer	28	0	0
Labourers, from 20 <i>l.</i> to 28 <i>l.</i> per annum	140	0	0
Shepherd	40	0	0
Farm servant and assistant	32	0	0
Horses, 20 at 1 <i>s.</i> 4½ <i>d.</i> per day	501	17	6
Cows, 30 at 1 <i>s.</i> per day	547	10	0
Sheep, 150 at 6 <i>s.</i> 4½ <i>d.</i> per day per 100	174	10	3½
Weeding, say, 6 <i>s.</i> 4½ <i>d.</i> per acre	79	13	9½
Seed, say, 8 <i>s.</i> per acre	100	0	0
Reaping, say, 9 <i>s.</i> 7½ <i>d.</i> per acre	120	11	5½
Thrashing, say, 4 <i>s.</i> 9½ <i>d.</i> per acre	60	3	1½
Chemical manure, say, 3 <i>s.</i> 2½ <i>d.</i> per acre	40	2	1
Farm manure 360 <i>l.</i> = its value as litter	—	—	—
Insurance of buildings and crops	10	0	0
Wear and tear of general plant, at 10 per cent.	160	0	0
Drawing lease	4	0	0
	2,973	19	5¼
Profit	126	1	2
	3,100	0	7¼

Some of the measures and prices in the above account are only approximate, but the sums carried out are exact.

What do we find here? That the yield of all crops is only middling—for wheat, 24 bushels of grain per acre; for rye, 22 bushels; for colza, 20; for grass land, 4,576 lbs. of hay. But I maintain that with 1*l.* 12*s.* worth of chemical manure per acre, in addition to the farmyard manure actually used, by an outlay of 400*l.*, taking the crops one with another, there would be a clear increase of value of from 1*l.* 5*s.* 7*d.* to 1*l.* 12*s.* per acre; the cost of the manure being subtracted, this would leave a profit of 400*l.* to 480*l.* instead of 126*l.*

Annual Receipts of a Farm of 250 acres.

Acres		£	s.	d.
85	Wheat, 24 bushels per acre, at 5 <i>s.</i> 10 <i>d.</i> per bushel	595	0	0
	3,520 lbs. of straw per acre, at 1 <i>s.</i> 7½ <i>d.</i> per cwt.	217	1	1
7½	Rye, 22 bushels per acre, at 3 <i>s.</i> 6½ <i>d.</i> per bushel	29	4	4½
	3,080 lbs. of straw per acre, at 2 <i>s.</i> 0½ <i>d.</i> per cwt.	21	1	1
20	Barley, 50 bushels per acre, at 3 <i>s.</i> 6½ <i>d.</i> per bushel	177	1	8
	2,816 lbs. of straw per acre, at 1 <i>s.</i> 0½ <i>d.</i> per cwt.	25	13	4
27½	Oats, 60 bushels per acre, at 2 <i>s.</i> 3½ <i>d.</i> per bushel	190	15	7½
	2,816 lbs. of straw per acre, at 1 <i>s.</i> 2¼ <i>d.</i> per cwt.	42	9	10½
22½	Beetroot, 1 ton 12 cwt <i>s.</i> per acre, at 7 <i>l.</i> 12 <i>s.</i> per ton	273	12	0
22½	Colza, 20 bushels per acre, at 8 <i>s.</i> 1 <i>d.</i> per bushel	181	17	6
	Haulm, at 14 <i>s.</i> 4 <i>d.</i> per acre	16	2	6
5	Flax, sold on ground at 16 <i>l.</i> per acre	80	0	0
45 {	Artificial meadow grass, 4,576 lbs. per acre, at 2 <i>s.</i> 5½ <i>d.</i> per cwt.	225	19	10
10 {	Winter fodder, 5,720 lbs. per acre, at 2 <i>s.</i> 5½ <i>d.</i> per cwt.	62	15	6
5 {	Potatoes, 132 bushels per acre, at 1 <i>s.</i> 9 <i>d.</i> per bushel	57	15	0
	Dairy produce	657	0	0
	Sheep	215	4	0
	Pigs and poultry fed on waste grain	48	0	0
	Farm manure (<i>nil</i>)	—		
		3,116	13	4½
Profit		142	13	11¼

The measures and prices in the above are only approximate, but the amounts carried out are exact.

The day is approaching when the only true manure will never be produced on a farm, but in those vast chemical manufactories, with high walls and tall chimneys, where Estremadura and Canada phosphates are broken up, rendered assimilable, and mixed with potash from granite or from the mines of Stassfurth, or with the sodic nitrate from Peru, or ammoniac sulphate from the gas works, so that every one,

great and small, may obtain the maximum crops the earth is able to produce.

Some time since, a gallant officer who was retiring from the service in order to become a farmer, asked me to give him some advice as to the best mode of proceeding.

The following was my reply: It is necessary that you should apparently be possessed of the very poorest farm in the canton, while in reality you will obtain the finest results. Be chary in building; buy only as many cattle as are necessary, in order to prepare the soil and provide for the needs of the farm. You tell me that wheat thrives on your land, then make wheat your first object of culture. With the grain you will make money, and have a good quantity of straw left on hand. If you have a few acres of low-lying grass land, manure it well; and, when to your reserve of straw you add a reserve of hay, the time will have come for you to think about buying cattle, and to fix on the number you ought to have. For a time sink no money, for ready cash is a tower of strength to the farmer. Plough well and deeply. Sow your cereals in lines of $7\frac{1}{2}$ inches apart; weed these with a small horse-hoe.

As Lavoisier justly says, and as common sense indicates, if we insist on following the opposite method and begin with cattle, risking the means of supplying them with food, a dry season alone is sufficient to ruin us; in which case only two alternatives are open: either to sell the cattle at a heavy loss or to purchase forage for them at an exorbitant price.

When, having weighed the subject well, the choice is made of raising cattle in preference to growing crops, it is necessary first to create a supply of food by means of chemical manure, so as to place yourself beyond all eventualities, and to remain master of the situation and have nothing to fear from the future.

It is necessary to keep your capital well in hand, and to risk as little as possible, in order to assure freedom of action—in other words, make agriculture a matter of commerce, instead of being a slave enchained, bowed down and curbed by the extinct feudal formula, *grass, cattle, cereals*. This formula had its day, but will never again be revived.

LECTURE XI.

FORMULÆ FOR MANURES, AND THE RULES RELATING TO THEIR APPLICATION.

THREE practical results are brought to light in the preceding lectures. The first is that, by the aid of four substances with which we are now familiar, we are able, not only to prevent the exhaustion of the soil, no matter how heavy the crops may have been which have grown on it, but also to endow it with the maximum of fertility consistent with the climate and general local conditions.

The second result to which we have been led is not less important than the first, viz., that farming, based upon the exclusive employment of farmyard manure, is never remunerative.

We must have equal growths of cereals and fodder; this is an absolute necessity, which is the result of the theory of chemical manures.

This brings us to a third result, relating to the rules necessary to be observed in order to manure the soil well. In former days the idea was to return to the soil, weight for weight, substance for substance, all that was taken from it. This is an error. Following out the theory of chemical manure, we have to return to the soil only calcic phosphate, potash, lime and half the amount of nitrogen that we have taken away; under this system the soil will produce maximum crops without being itself weakened thereby.

These three results show the superiority of the new over the ancient method. But in order to draw from the new method all the advantages that it possesses, it is not only necessary to know exactly the substances which induce fertility in the soil; we must know also the practical rules that govern their use. Here, again, everything is irresistibly simple and clear.

From what we have already seen it is evident that when we wish to obtain the maximum of results at the least cost, it is necessary to vary the composition of the manure in order to suit the needs of each class of plants. This selection cannot be made until we have first discovered the degree of richness of the natural soil.

I will now pass on to speak of the wants of each plant independently, and of the nature and influence of the locality in which it is grown. It is necessary to ascertain the dominant mineral constituent of each plant, and find out by experience the amount of manure necessary to obtain at will ordinary or maximum yields.

The first point—the discovery of the dominant constituent—is not difficult. Plants are divided into three categories—first, those in which nitrogenous matter is the dominant constituent, such as cereals, hemp, colza, beetroot and general garden stuff. The second group, of which phosphate is the preponderating ingredient, comprises maize, sugar-cane, Jerusalem artichokes, turnips and sorghum. Lastly, leguminous plants, clover, sainfoin, lucern, potatoes and vines have potash for their dominant constituent. This first point being once established, we have next to fix the most suitable quantities, both of the dominant and the subordinate constituents. To determine this point, I have since 1860 conducted many thousands of experiments, and I am now in a position to classify all manures into five distinct groups:—

1. Normal manure.
2. Homologous manure.
3. Stimulating manure.
4. Incomplete manure.
5. Manure with special functions.

Let us first consider the nature and character of this division.

Normal manures contain calcic phosphate, potash, lime and nitrogenous matter, and differ only in the respective proportions of these four substances. By varying their relative proportion in these manures according to the necessities of the particular plants for which they are required, we can apply the principle of dominant constituents to every possible condition which may arise, thereby meeting the requirements and advancing the interests of every description of farming.

Six normal manures are distinguished by their number:—

				Dominant constituents	Crops are
Normal manure, No. 1	.	.	.	Nitrogen	Cereals
" "	2	.	.	"	Beetroot
" "	3	.	.	Potash	Potatoes
" "	4	.	.	"	Vines
" "	5	.	.	Calcic phosphate	Cane sugar
" "	6	.	.	No dominant	Flax

Immediately after the normal manures come the homologous manures, which form two parallel series—the one designated by the letter A, and the other by the letter B.

In the normal homologous manure marked No. 1 A, a mixture of potassic chloride and ammoniac sulphate replaces the potassic nitrate; the richness is the same in either case; the form in which the potash and a part of the nitrogen occur is the only difference.

Here is an example:—

Normal Manure, No. 1.

	Per acre lbs.
Calcic superphosphate	352
Potassic nitrate	176
Ammoniac sulphate	220
Calcic sulphate	308
	<hr/>
	1,056

Normal Homologous Manure, No. 1 A.

Calcic superphosphate	352
Potassic chloride, 80°	176
Ammoniac sulphate	343
Calcic sulphate	185
	<hr/>
	1,056

We will pass to the homologous manures of symbol B. These differ from the corresponding manures in the form of the phosphatic element; instead of calcic superphosphate, $\text{CaH}_4\text{P}_2\text{O}_4$, it contains calcic phosphate with two equivalents of base $\text{Ca}_2\text{H}_2\text{P}_2\text{O}_4$, which is termed precipitated or dibasic phosphate.

This is still identical as to richness, the difference being only in the form of the phosphate:—

Normal Manure, No. 1.

	Per acre lbs.
Calcic superphosphate	352
Potassic nitrate	176
Ammoniac sulphate	220
Calcic sulphate	308
	<hr/>
	1,056

Normal Homologous Manure, No. 1 B.

Precipitated phosphate	158
Potassic nitrate	176
Ammoniac sulphate	220
Calcic sulphate	326
	<hr/>
	880

In fact, if it were found desirable to associate potassic chloride with precipitated phosphate, we should have to use the formula No. 1 C.

Normal Homologous Manure, No. 1 C.

	lbs.
Precipitated phosphate . . .	158
Potassic chloride, 80° . . .	176
Ammonic sulphate . . .	343
Calcic sulphate . . .	203
	<hr/> 880

Lime being everywhere in excess, we are not constrained to keep it rigorously to the same dose, but where it is simply necessary to give a formula containing sufficient manure for 1 acre of ground, a weight that varies from 880 to 1,056 lbs. is sufficient; thus the homologous manures are of exactly the same composition and the same richness as the normal manure.

In devising these formulæ, I have had two objects in view—to give greater efficiency to the manure, and to realise a decided economy. In potassic nitrate there is in round numbers of

	Per cent.
Nitrogen	14
Potash	47

For two or three years this salt was worth from 1*l.* 12*s.* to 1*l.* 13*s.* 7*d.* per cwt. Now with ammonic sulphate at 1*l.* per cwt., and potassic chloride at 10*s.* per cwt., it was possible for 1*l.* 4*s.* to obtain the equivalent of 1 cwt. of potassic nitrate:—

	£	s.	d.
77 lbs. of ammonic sulphate . . .	0	14	0
1 cwt. of potassic chloride, 80° . . .	0	10	0
	<hr/> £1	4	0

It is a remarkable thing that the new manure has generally shown itself to be more efficacious than that previously used for cereals and grass. Originally I used potassic nitrate for sainfoin, clover, lucern and the leguminosæ, but experience having shown that these plants do not need nitrogen—potassic chloride alone, without the addition of ammonic sulphate, is found to be equally efficacious, from whence results a still more important economy. Potassic nitrate at the present time is worth at least 1*l.* 6*s.*, and potassic chloride at the most 10*s.* per cwt. The same obser-

vation applies also to calcic superphosphate. On soil newly brought into cultivation the superphosphate, which is, however, in the great majority of cases the most efficacious of phosphatic compounds, is too soluble. In special cases it is preferable to substitute the precipitated phosphate for it, which to the merit of more certain action adds that of being considerably less expensive, for in the calcic superphosphate the phosphoric acid costs $4\frac{1}{3}d.$ per lb., and in the precipitated phosphate only $2\frac{1}{2}d.$

By the term stimulating manure must be understood a normal manure in which we have increased the dose of the dominant constituent in order to obtain the maximum results, when the season admits of their employment. I take as examples the normal manure No. 2, and the normal stimulating manure No. 2.

Normal Manure, No. 2.

	Per acre lbs.
Calcic superphosphate	352
Potassic nitrate	176
Sodic nitrate	264
Calcic sulphate	264
	<hr/>
	1,056

Normal Stimulating Manure, No. 2.

Calcic superphosphate	352
Potassic nitrate	176
Sodic nitrate	396
Calcic sulphate	220
	<hr/>
	1,144

Nitrogen is the dominant element in beetroot, therefore by raising the dose we insure an increase in the crop, provided the season is sufficiently moist. In the normal manure the quantity of nitrogen was $63\frac{1}{4}$ lbs., in the stimulating it was increased to $75\frac{3}{4}$ lbs. Again, there are cases where the earth, from its geological origin or from alluvial deposits, possesses an exceptional richness in phosphates, potash or nitrogen; on these soils, therefore, it is not necessary to have recourse to the normal manures in order to obtain good crops; and we may suppress for a time that particular constituent with which it is fully provided.

But here again it is necessary to avoid the uncertainty of rule of thumb and the hard and fast lines of preconceived ideas; to avoid this double danger, I have created the revised formulæ for what I call incomplete manures, which are derived

from the normal manures, but which differ from them in the suppression of one of the two constituents, potash or nitrogen.

To this end I will, in passing, again call your attention to the contrast which exists between cereals and leguminous plants. Before the great value of potassic chloride was known to me I advised that potassic nitrate, which contains 14 per cent. of nitrogen, should be used for the leguminosæ. Since it has been demonstrated to me that potassic chloride is quite as good as potassic nitrate for peas, beans, clover, sainfoin and lucern, I have not hesitated to give the preference to it, which effects a saving of at least 1*l.* 5*s.* 7*d.* per acre. Here, then, are four series of manures each responding to one special requirement. In the one instance it is the natural richness of the soil, in the other an idea of economy that determines our choice, but whatever the motive

of our decision the result is always assured, because our formulæ are all derived from those of the normal manures, which are the types, so to speak, of the mineral food of various kinds of plants.

In the last place comes a class of manures the formulæ for which have not been published, which we shall call manure with specific functions, or special manures. These not only act upon the quantity but also upon the quality of the crops. Let us suppose it is possible to produce effects of two kinds, to affect at the same time the quantity of the crop, the quantity of grain in the crop, and the amount of gluten in the grain. Let us suppose again that with beetroot it is

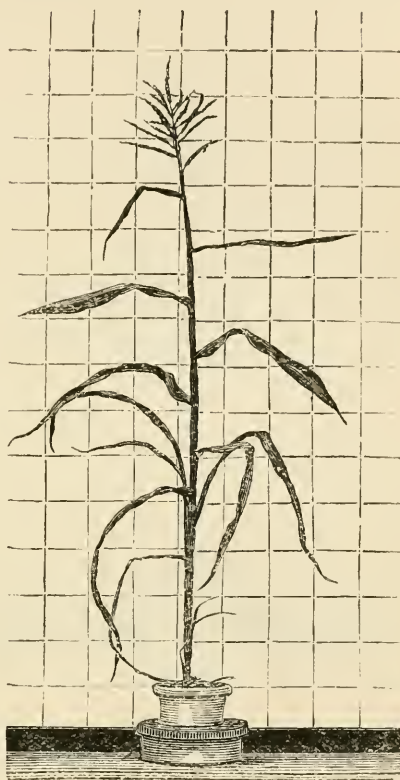


FIG. 5.

possible to influence at the same time the extent of the crop and the saccharine richness of the roots. These effects being obtained by means of special manures, would lead to the discovery of three new classes of manure, namely :—

Grain Manure.

Gluten „

Sugar „

What first led me to this supposition was the hope that in the future and at no very distant period we may be successful in producing effects of this kind. You will permit me to justify my hopes on this point.

Refer to the illustrations of the two cultures of maize plants growing in calcined sand. In one the plant has attained a height of 50 or 60 inches before bearing grain; in the other the stalk has stopped at 35 inches, and has borne seed.



FIG. 6.

The contrast is instructive, and the cause is not far to seek. In the first case the manure contained potash in the form of potassic chloride, and in the second in the state of potassic sulphate. In 1873 two experiments made at Vincennes under similar conditions gave like results.

Manure with Potassic Chloride.

	Per acre	
	Tons	Cwts.
Stalk . . .	5	16
Husk . . .	1	6
Grain . . .	3	14
Leaves . . .	2	10
	13	6

or 66 bushels.

Manure with Potassic Sulphate.

	Per acre	
	Tons	Cwts.
Stalk . . .	5	4
Husk . . .	1	17
Grain . . .	5	0
Leaves . . .	2	13
	14	14

or 73 bushels.

Judging from these results, my first thought was that the potassic sulphate exercised a specific action upon the for-

mation of the grain, but I have since learnt that by slightly augmenting the quantity of nitrogen as much grain is obtained with the potassic chloride as with the potassic sulphate.

Here then is a first indication that deserves above all to be pointed out to you.

It has for a long time been known that manures rich in nitrogen increase the proportion of gluten in cereals, Hermbstaëdt, Tesaier, Boussingault have fixed this increase at from 12 to 13 per cent.; I have myself verified the exactness of the fact, although with smaller results.

On one plant in particular, viz., beetroot, I have varied my experiments *ad infinitum*, in the endeavour to increase its saccharine richness, and have, three times out of five, obtained richer roots with potassic chloride associated with ammonic sulphate than with potassic nitrate. These first experiments justify my hope of one day seeing specific functional manures practically applied.

We will pass now from the general classification of manures and their reciprocal relations to the study of the rules to be observed in selecting the formulæ best suited to each kind of plant. These rules are necessarily a repetition of those which I have already laid before you, namely, to know the dominant constituent of a plant, the proportion it is necessary to employ, and the proper proportion of the subordinate constituents. We will begin by speaking of those plants in which nitrogen is the dominant constituent. Colza, for example, requires from 66 to 70 lbs. of nitrogen per acre, and of the subordinate elements,

	lbs.
Phosphoric acid	52
Potash	79 to 97
Lime	97 to 194

With such a manure and by adopting certain rules that I shall presently lay down, we are sure, unless the year be unfavourable, to obtain from 33 to 44 bushels of grain per acre; the total weight of the yield being about 10 tons 10 cwts.

The knowledge of these requirements leads to the two following formulæ:—

Normal Manure, No. 1.

	Per acre lbs.
Calcic superphosphate	352
Potassic nitrate	176
Ammonic sulphate	220
Gypsum	308
	<hr/> 1,056

Normal Homologous Manure, No. 1 A.

	Per acre
Calcic superphosphate	352
Potassic chloride	176
Ammonic sulphate	343
Gypsum	185
	<hr/> 1,056

Here is an account of two crops obtained in the experimental field with the normal manures No. 1 and No. 1 A:—

<i>Normal Manure, No. 1.</i>			<i>Normal Homologous Manure,¹ No. 1 A.</i>		
		Per acre Tons Cwts.			Per acre Tons Cwts.
Stalk		4 2	Stalk		3 15
Husk		1 18	Husk		1 13
Grain		1 15	Grain		1 14
		<hr/> 7 15			<hr/> 7 2

In each case the manure contained 67 lbs. of nitrogen per acre. Let us carry our investigation still further and make two parallel experiments, one with mineral manure composed of calcic phosphate, potash and lime, to the exclusion of nitrogen, and the other with a normal manure containing both nitrogen and mineral matter, and then draw the conclusion that must arise from the results being compared:—

	Grain per acre Bushels
With the normal manure	43
„ mineral manure, without nitrogen	16½

Under equal conditions the nitrogenous matter had sufficed to raise the yield from 16½ to 43 bushels. In making a third experiment, instead of 67 lbs. of nitrogen give only 35 and the yield will fall from 43 to 27½ bushels, an excess of 11 instead of 26½. Let us now look at these results from a financial point of view, and find out what nitrogenous matter is worth, and what, on the other hand, is the value of the excess of 11 and 26½ bushels of grain which we have gained by its use.

In the first case the excess of the crop is 11 bushels:—

	£	s.	d.
11 bushels of colza, at 7s. 3¼d., say	4	0	0
35 lbs. of nitrogen, at 11d., say	1	12	0
	<hr/> £2	8	0

¹In the autumn this crop was much the finer of the two, but the winter tried it more than its neighbour.

In the second case the excess is $26\frac{1}{2}$ bushels:—

	£	s.	d.
26½ bushels of colza, at 7s. 3½d.	9	12	8
70 lbs. of nitrogen, at 11d.	3	4	2
	<hr/>		
	£6	8	6

But this is not all: in order to obtain these remarkable results, one precaution must always be taken. It is necessary to divide the nitrogenous material into two doses, giving one in the autumn and the other in the spring. If we give the nitrogenous material all at one time, in the autumn, the plant at first acquires great development: the leaves are larger and thicker, but they all fall with the first frost, and the nitrogenous material that had determined their formation is lost to the plant.

If, on the contrary, we give the half only of the nitrogenous material in the autumn and half in the spring, we find, as it were, that the growth of the plant is irresistibly impelled, and the addition to the herbaceous parts formed at the last moment react in their turn upon the importance of the grain crop.

Here is a remarkable example borrowed from results obtained in 1874:—

	Grain per acre	
	Bushels	
70 lbs. of nitrogen, in two doses	43	
„ „ „ one dose	34	

—that is, 9 bushels in excess, on account of the dominant element being better managed. In the presence of such facts, who will be bold enough to deny the importance of the ideas which we are investigating? We will now speak of wheat, that source of wealth *par excellence* of nations.

Here, again, nitrogen is the dominant constituent, but this time it is necessary to employ it with greater care and circumspection than with colza, 53 lbs. per acre being generally sufficient.

If more than this quantity is used, the plant becomes too green, and it is almost inevitably “laid” by the rain and wind, which is always attended with disastrous consequences.

A not less essential precaution is the further division of the nitrogen into two doses, $26\frac{1}{2}$ lbs. in the autumn and $26\frac{1}{2}$ lbs. in the spring. This condition is fulfilled in the two following formulæ:—

AUTUMN.

Normal Homologous Manure, No. 1 A.

	Per acre lbs.
Calcic superphosphate	176
Potassic chloride, at 80°	88
Ammonic sulphate	171
Gypsum	93
	<hr/> 528

In the spring apply ammonic sulphate from 44 to 132 lbs.

Let us now proceed to the consideration of beetroot, in which, again, nitrogen is the dominant element. If the beetroot is to be used as fodder, sodic nitrate is more efficacious, and must therefore be substituted for ammonic sulphate. With beetroot, we have not to fear "laying," as with wheat, so that the dose of nitrogen may be increased to 70 or even 88 lbs. per acre, by successive additions of ammonic sulphate, provided the summer is both damp and warm. I will show by a fresh example, that the increase in the crops and the profit again depends essentially upon the dose of the dominant constituents:—

	Result per acre Tons Cwts.
Mineral manure	12 8
Normal manure, with 70 lbs. of nitrogen	18 16
" " 88 " 	20 8
" " 105 " 	23 12

—the profit being in proportion to the increase in the crop. Now you know precisely the manures of which nitrogenous material is the dominant principle. I will conclude with a recapitulatory table of the quantity of nitrogen that it is necessary to employ for each kind of plant:—

	lbs. per acre
Colza and hemp	70
Wheat	53
Barley, rye, oats	35
Beetroot	70

I now pass to those manures the dominant constituent of which is potash, and I take potatoes for my example. This crop, which is almost equal in importance to wheat, presents an exceptional interest by reason of the ill effects that attend insufficient or badly composed manure. By the following table, you will see in what degree the potato is influenced by potash. In 1865 the manure contained 103 lbs. of nitrogen, in 1867 only 67 lbs.

	Result per acre			
	1865		1867	
	Tons	Cwts.	Tons	Cwts.
Normal manure . . .	11	3½	9	16¾
Manure without lime . .	9	6½	8	4
„ phosphate . . .	7	3	—	—
„ nitrogen . . .	6	14	8	6¾
„ potash . . .	4	4	4	4
Without any manure . .	3	1½	3	0

The suppression of potash causes the crop to diminish from 9 tons 16¾ cwts. to 4 tons 4 cwts., the soil without manure yielding only 3 tons. But this is not all. You will see by the preceding table, that by reducing the proportion of nitrogen in the normal manure from 103 to 67 lbs. per acre, we only obtain

		Tubers per acre	
		Tons	Cwts.
With 103 lbs. of nitrogen		11	3½
„ 67 „ „		9	16¾

By suppressing the potash in the two manures, the results became equal. The excess of nitrogenous matter was altogether useless, and no longer exercised any action.

Manure without Potash.

		Potatoes per acre	
		Tons	Cwts.
With 103 lbs. of nitrogen		4	4
„ 67 „ „		4	4

The suppression of calcic phosphate causes the crop to decrease from 11 tons 3½ cwts. to 7 tons 3 cwts.

If now we make another experiment, suppressing the calcic phosphate and doubling the dose of potash, the yield will reach 11 tons 3½ cwts.

		Potatoes per acre	
		Tons	Cwts.
Normal manure, with 103 lbs. of nitrogen		11	3½
Manure without calcic phosphate		7	3
„ „ but with double dose of potash		11	4

A remarkable example of the preponderant action of the dominant constituent. The practical conclusion to be drawn from all this is, that 132 lbs. of potash per acre are necessary for potatoes, in place of the 44 lbs. which suffice for wheat, thus leading us to the Normal Manure, No. 3:—

Normal Manure, No. 3.

	Per acre lbs.
Superphosphate	352
Potassic nitrate	264
Gypsum	264
	<hr/> 880

But this is not all. I have announced to you certain facts of an altogether new order. You know that vegetables, like animals and even mankind, are subject to parasitic and infectious diseases.

Who does not remember the terrible effects produced in Ireland by the potato disease at the time of its first outbreak? I shall say nothing of the explanations that have been given of these formidable scourges. Whether the parasites are the cause or the effect of the evil, whether they owe their origin to microscopic germs floating in the atmosphere, or result from the evolution of cells of certain tissues which become independent of the relatively superior organism of which they form a part, and live henceforth a life of their own; whatever be the explanation that is generally accepted, one certain fact, inflexible in its manifestations, governs all, viz., that the absence, or, at any rate, scarcity in the soil of certain elements indispensable to the life of plants, multiplies if it does not absolutely give rise to those diseases of which we have just been speaking. For six years these phenomena at Vincennes have not changed. Wherever the soil does not receive potash, or where it gets no manure, the plants are poor and stunted, withered and dry black leaves, and that, too, in the month of June, when the other plantings are still in a state of luxuriant growth. As for the tubers, they become wrinkled, withered and reduced in size,¹ their preservation being almost impossible.

Vines are subject to similar effects; and although my experience is less extended in this direction, it enables me to be equally positive. Where potash is lacking, the leaves do not attain their full development; in the month of July they become red and spotted with black, after which they become dry and are easily reduced to powder under pressure of the fingers.

The stem does not reach a fourth of the dimensions it attains with the normal manure. I have not yet been able to collect evidence on the production of the fruit. You see by these examples the great practical importance

¹ See my pamphlet on the potato disease (*Librairie Agricole*).

of the questions of proportions and formulæ, and what care it is necessary to exercise in order to discover the dominant constituents of plants, and to regulate their quantity. You will remark, further, that in all this we have formed no hypothesis, that our judge and guide is always experience, having for her surety the leaders of the agricultural world. To the objections that I encounter, I oppose but one argument—Experience!

To my opponents I say—Instead of exhausting yourselves with fine talking, make a few experiments on a small scale, which not only entail no loss, but which, when performed with the necessary care, carry conviction to the mind, because they bring to light the contrasts in growth that I have been explaining. A small experimental field is an auxiliary that defies all argument. To all the hostile arguments directed against the new method the practical man replies, My experimental field tells me to the contrary, *e pur si muove*; the plant grows and increases in size in the way foretold and with the desired celerity.

Amongst manures in which potash is the dominant constituent, those which are of service to the leguminosæ merit our attention. In my lectures of 1864 and 1868 you will find discussions upon this remarkable faculty possessed by leguminosæ of being very little affected by nitrogenous substances. From this I immediately came to a practical conclusion, which was not to give nitrogen to leguminosæ, but to give potash instead.

Originally I employed the following manure for these plants:—

Normal Manure, No. 6.

	Per acre lbs.
Superphosphate	352
Potassic nitrate	176
Gypsum	352
	<hr/>
	880

in which the nitrogen amounted to 22½ lbs., but I now prefer to use this formula:—

Incomplete Manure, No. 6.

	Per acre lbs.
Superphosphate	352
Potassic chloride, at 80° . .	176
Gypsum	352
	<hr/>
	880

which makes a saving of 1*l.* 5*s.* 7*d.* per acre, and is not less efficacious than the first.

On poor ground, or when lucern or clover is concerned, it is an advantage to increase the dose of potassic chloride to 264 lbs.

I now come to the last category of normal manures—those in which the dominant constituent is calcic phosphate.

Here the economical part of the question acquires increased importance, because, the superphosphate being the least expensive of the four substances forming the normal manure, and its efficacy being in certain cases very great, a slight increase of expenditure suffices to obtain a large excess of the crop.¹

With the normal manure No. 6, M. de Jabrun, of Guadeloupe, obtained 18 tons of sugar-cane, stripped of leaves, per acre.

With an increase of 176 lbs. of superphosphate the result was raised to 38 tons, an excess of 14 tons of cane valued at from 11*l.* 4*s.* to 12*l.* 16*s.*, the increase of expenditure being about 12*s.* 9*d.* This seems almost beyond belief, but experience has conclusively confirmed the truth of the statement.

To regulate the composition of manures with certainty, three precepts will suffice.

First of all, be sure of the dominant constituents, and the proportions in which it is necessary to employ them, in order to obtain the maximum of their useful effects; secondly, know the proportion of the subordinate constituents which these same dominants require in order to bring out their action; and lastly, only draw conclusions from the testimony of experiment.

This, then, is the only method by which we can determine the composition of manures and devise their formulæ.

Let us now speak of incomplete manures, which comprise manures without nitrogen and manures without potash. I have but little that is special to say on this subject, except, as you have already been informed, they may be used for leguminosæ; in other cases their use is only possible when the soil is naturally provided with nitrogen and potash, which it is always easy to discover by means of the practical experiments which I have described in former lectures. Thus, by the aid of three series of manures, viz., normal manures, stimulating manures and incomplete manures, all the wants of practical agriculture can be provided for. We have, up

¹ Superphosphate is cheaper than nitrogen compounds, and than salts of potash, but it is of course much dearer than gypsum.

to the present time, spoken of manures with respect to the wants of each particular description of plants, but in practice things do not happen thus; we very rarely cultivate any particular species of plants year after year on the same spot, but proceed generally by alternation or rotation of crops. In this case, as in the preceding one, do we use the normal manure for each plant? No. It is only necessary to use it every other year, and to use the dominant constituent only at intermediate times, as sufficient of the subordinate constituents remain in the soil to insure the success of the second crop. For greater precision I will quote an example. This is an alternation of four years:—

1st year, beetroot	. normal manure, No. 2, or No. 2 A.
2nd „ wheat	. ammonic sulphate.
3rd „ potatoes	. normal manure, No. 3.
4th „ wheat	. ammonic sulphate.

If in the third year clover, which requires no nitrogen, had been grown instead of potatoes, we should have replaced the normal manure No. 3 by the new incomplete manure No. 6, which does not contain nitrogen, and the rotation would become:—

1st year, beetroot	. normal manure, No. 2, or No. 2 A.
2nd „ wheat	. ammonic sulphate.
3rd „ clover	. manure without nitrogen (incomplete, No. 6).
4th „ wheat	. ammonic sulphate.

That is to say,

First Year.

BEETROOT.

	Quantity lbs.	Per acre Cost £ s. d.		
Normal homologous manure, No. 2 A, 1,056 lbs.				
Calcic superphosphate	352	0	15	4
Potassic chloride, at 80°	176	0	14	1
Ammonic sulphate	123	1	0	2
Sodic nitrate	264	1	10	9
Gypsum	141	0	1	0

Second Year.

WHEAT.

Ammonic sulphate	264	2	3	2
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Third Year.

CLOVER.

Incomplete manure, No. 6, 880 lbs.				
Calcic superphosphate	352	0	15	4
Potassic chloride, at 80°	176	0	14	1
Gypsum	352	0	2	7

Fourth Year.

WHEAT.

	Quantity lbs.	Per acre Cost		
		£	s.	d.
Ammonic sulphate	176 to 264	2	3	2
Expenses for four years		9	19	8
Mean expenses for one year		2	9	11

We thus supplement the system of the rotation of crops by the alternation of manures.

Let us dwell a little on this point. 1st year beetroot: with the normal manure No. 2, or its homologue, No. 2 A. All its nitrogen is absorbed, but as the leaves are left to rot in the field, enough mineral matter is left for one crop of wheat. Thus the same year ammonic sulphate only need be used. The same holds good for the two following crops, clover and wheat.

Clover draws its nitrogen from the air, therefore the incomplete manure, which does not contain nitrogen, is all it requires. Wheat, which succeeds it, needs in reality only nitrogenous matter, and by reason of the detritus which the clover has left the dose may be restricted.

You will find in the first part of my lectures (p. 50) the combination of manure best suited to the principal alternations of crops. To enumerate them would be useless, since all the series we based upon the same rules.

We will now speak of the best methods of applying chemical manures. I used formerly to apply the whole of the chemical manure at once, in the same way that it was customary to employ farmyard manure, but I have been led to see the inconvenience of the system.

In the first place it required a considerable amount of capital in the form of ready money for the chemical manure. The manure for one rotation of four years would exceed the means of a large number of farmers. But this is not all; during dry years an excess of manure is more inconvenient than advantageous. Of what use is it to load the soil with manure that could not be utilised by the first crops? Another inconvenience was that with certain plants, wheat for example, an excess of manure during moist seasons would certainly cause the crop to "lay". To escape this double danger I at first had recourse to alternate and then to graduated and progressive manurings.

I will show by an example the difference which exists between the three methods of working. By the first method all the manure for two years was put on at one time.

First Year, in Autumn.

	Per acre lbs.
Calcic superphosphate	352
Potassic chloride, at 80°	176
Ammonic sulphate	607
Gypsum	185
	<hr/>
	1,320

Second Year.

No manure.

SECOND METHOD, BY ALTERNATE MANURING.

First Year, in Autumn.

	Per acre lbs.
Normal Homologous manure, No. 1 A, 1,056 lbs.	
Calcic superphosphate	352
Potassic chloride	176
Ammonic sulphate	343
Gypsum	185
	<hr/>
	1,056

Second Year, in Autumn.

Ammonic sulphate	264
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THIRD METHOD, GRADUATED AND PROGRESSIVE MANURING.

First Year, in Autumn.

	Per acre lbs.
Normal Homologous manure, No. 1 A, 528 lbs.	
Calcic superphosphate	176
Potassic chloride, at 80°	88
Ammonic sulphate	171½
Gypsum	92½
	<hr/>
	528

Same Year, in Spring.

Ammonic sulphate.	88 to 176
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You will readily perceive the superiority of the third method.

With the first method, that of using a large quantity at and in one application, the outlay is great and accidents frequent. The defect of the second method is that the expenditure is still considerable on account of the surplus mineral matter given without necessity to the first crop. In the third method we escape these two defects. The dose of mineral matter is strictly what it should be; as for the nitrogen it is graduated according to the character of the season, and care is taken to maintain proper relation between external conditions and the quantity of manure.

Then for cereals I never hesitate, but let there be always top-dressing in the autumn as well as in the spring. This time the dose of ammoniac sulphate is regulated according to the state of the crops, the dose being increased where the growth is weak, and diminished where it is stronger. There is no necessity for insisting further on this, for the precautions will, as it were, be imposed upon us by their own evidence. Let us now return to the homologous manures, and inquire whether being equal to the normal manures in richness they are also equal in efficacy. I would remind you that in the homologous manures of the No. 1 A type, the potassic nitrate is replaced by a mixture of potassic chloride and ammoniac sulphate. One great advantage of these manures is that they are considerably less expensive. This year the difference is not great; but last year it was considerable, and I do not hesitate to attribute in part the fall of the prices of nitrates to the introduction of the new formulæ.

At the present price

	£	s.	d.
62 lbs. of ammoniac sulphate costs . . .	1	2	2
88 lbs. of potassic chloride, at 80° . . .	0	15	5
	<hr/>		
	£1	17	7

for replacing 88 lbs. of potassic nitrate, of which the price is 2*l.* 2*s.* 3*d.*, while last year it was 2*l.* 16*s.* 3*d.*

Comparison between Normal and Homologous Manures.

WHEAT.							
Year				Homologous Manure, No. 1 A New Formula	Normal Manure No., 1 Old Formula		
				Per acre	Per acre		
1870	{	Straw	.	.	.	lbs. 3,902	lbs. 3,142
		Husk	.	.	.	598	480
		Grain	.	.	.	2,399 = 37 bush.	2,626 = 40½ bush.
						6,899	6,248
OATS.							
1871	{	Straw	.	.	.	5,552	5,519
		Husk	.	.	.	521	548
		Grain	.	.	.	2,515 = 76 bush.	2,468 = 73 bush.
						8,588	8,535
WHEAT.							
1872	{	Straw	.	.	.	5,733	5,044
		Husk	.	.	.	462	597
		Grain	.	.	.	3,978 = 62 bush.	3,458 = 54 bush.
						10,173	9,099
WHEAT.							
1873	{	Straw	.	.	.	3,937	3,511
		Husk	.	.	.	746	651
		Grain	.	.	.	2,233 = 34 bush.	1,980 = 30 bush.
						6,916	6,142

Mean Result of Four Years.

Crop			Crop		
Total result	.	8,144 lbs.	Total result	.	7,506 lbs.
Grain	.	52 bush.	Grain	.	48 bush.

But I must return to my first question.

Setting aside the price, are the homologous manures as efficacious as the normal manures? Four consecutive years' experience, both with wheat and beetroot, lead me to give the preference to the former.

BEETROOT.

Homologous Manure, No. 2 A						Normal Manure No. 2		
Year					New Formula		Old Formula	
					Tons	Cwts.	Tons	Cwts.
1867	Roots	.	.	.	21	6	18	11
1868	„	.	.	.	12	18	11	14
1869	„	.	.	.	15	6	13	17
1870	„	.	.	.	16	10	14	0
					66	0	58	2
	Mean	.	.	.	16	10	14	10½

PEAS.

1873 {	Straw Grain	Incomplete Manure, No. 6, with potassic chloride		Normal Manure, No. 6, with potassic nitrate	
		Per acre		Per acre	
		lbs.		lbs.	
		2,992 2,464		3,520 2,640	2,992 2,288
		5,456 = 37 bush.		6,160 = 41 bush.	
				5,280 = 35 bush.	

BEANS.

1873 {	Straw Grain	With potassic carbonate	Manure with potassic chloride	With potassic nitrate
		Per acre	Per acre	Per acre
		lbs. 3,766 1,654	lbs. 3,824 1,720	lbs. 3,173 1,438
		5,420 = 24 bush.	5,544 = 24 bush.	4,611 = 21 bush.

Soil without Manure.

Straw	.	.	.	lbs. 1,280
Grain	.	.	.	762 = 11 bushels
				<hr/> 2,042

With peas and beans the potassic chloride, without the addition of ammoniac sulphate, is shown to be quite as efficacious as potassic nitrate.

The advantage is always on the side of the homologous manures. It is unnecessary to add that the crop of oats, being reckoned in the average of four years, somewhat exaggerates the importance of the crops of wheat.

I would remind you that with the homologous manure composed of potassic chloride and ammoniac sulphate, beet-root is generally richer in sugar than with manure consisting of potassic nitrate. This fact has been verified by M. Corenwinder in the neighbourhood of Lille, and by M. Pagnohl at Anas.

We may then consider it definitely settled, but through an excess of caution I present it only as a first indication. You have seen that with peas and beans potassic chloride yields in nothing to potassic nitrate. I bring the results before you again because it is here that the advantages of the new formula are particularly marked. They produced a saving of from 1*l.* 5*s.* 7*d.* to 1*l.* 12*s.* per acre.

Peas.

	Per acre Bushels
Manure, with potassic chloride . . .	37½
„ with potassic nitrate . . .	35

For colza the new formulæ are also better than the old.

You may perhaps say to me, So far all is well. We know the formula of manures suitable to each kind of plant; we know how to vary their application when we wish to have continuous or alternate crops, but we are absolutely ignorant how to proceed when the chemical manures are to be used in conjunction with farmyard manure. What rules are to be followed in this case, which is the one that most frequently occurs? They may be deduced from those I have already put before you.

If the quality of manure that you produce is very large, say 4 or 5 tons per acre per year, add successively to the farmyard the dominant constituent of each of the plants comprised in the alternation. If the alternation is begun with a crop of barley and colza, 176 lbs. of ammoniac sulphate will be used; if it is beetroot, from 180 to 250 lbs. of sodic nitrate, and so on with the others. You see the cases are changed, the special conditions are modified, but the rules always remain the same, and suffice for all necessities. Indeed it could hardly be otherwise, seeing that these rules are laid down by the plants themselves.

The modern system of scientific agriculture has for its foundation the artificial production of plants by the help of simple chemical compounds in defiance of all the traditions which the old system has handed down to us. From the day on which the modern system was first practically adopted chemists, far from forbidding the use of farmyard manure, have simply advised farmers to abstain from using manures which are too strong for their particular purpose, but to rectify and complete the imperfect composition of farmyard manure by the addition of chemical compounds, which is a very different matter. Finally, we cannot pass over in silence the new means that the association of chemical manures with farmyard manure gives to the agriculturist. Let us suppose a sowing of colza and of wheat well manured; the winter has been rigorous, the spring late, and the plants have suffered. With farmyard manure only you could do nothing, and the yield would be bad. It is not possible to spread on the land more farmyard manure during the month of March, besides, if it could be done, its action would be radically *nil*. The farmer is thus condemned to remain an impassive spectator of an inevitable mistake.

But if, on the contrary, chemical manure be added to the farmyard manure, all will be changed; 176 lbs. of ammoniac sulphate per acre will suffice to give a sudden impulse to the colza and the wheat, and the result is certain.

The last part of the question is financial: the relative cost

of farmyard manure and chemical manure. The market prices are as follows:—

	Per cwt.		
	£	s.	d.
Ammonic sulphate	0	18	0
Sodic nitrate	0	12	10
Potassic nitrate	1	4	0
Potassic chloride, at 80°	0	8	10
Superphosphate	0	4	10
Precipitated phosphate	0	7	2

The price of the compound manures can be readily gathered from that of simple manures; but though these indications answer to a concrete idea, it is necessary to ask the cost of as much chemical manure as is equivalent to a ton of farmyard manure. This question is happily no more difficult to solve than the former one was. Here is the deduction.

In 1 ton of farm manure there are, roughly speaking,

	lbs.
Nitrogen	8 $\frac{3}{4}$
Phosphoric acid	2 $\frac{3}{4}$
Potash	8 $\frac{3}{4}$
Lime	17 $\frac{1}{2}$

This, according to the price I have indicated for isolated chemical products, represents a value of 10s. 6d.

Since 1867 this price has been subject to fluctuations; at first it was very high and continued so, because then the consumption exceeded the means of production.

But in proportion as the market has kept up and increased the demand, chemical industry acted on in its turn has set itself, as it were, to respond to the demand, and so well has it succeeded that by an inevitable reaction a general fall has taken place in the price on all products, and at the present time they are cheaper than they were in 1867, notwithstanding that the consumption is ten times larger.

LECTURE XII.

THE COST OF ANIMAL OR FARM MANURE—ITS EFFECTS COMPARED WITH CHEMICAL MANURE—LOCALITY OF THE FARM.

THE cost of animal or farm manure has already been very fully treated in the fifth Lecture of this work ; but the question being of a most important nature, it will be necessary, at the risk of recapitulating a part of what has been already said, to go into it once more at some length. It will be as well to remind the reader that since 1867 the cost of an amount of chemical manure equivalent to a ton of farm manure has fallen from 11s. 4*d.* to 10s. 5*d.*

I have already shown in my lectures in 1867 (see p. 65) the defective principles adopted by M. Boussingault on his farm at Bechelbronn. If you wish to place the agricultural question clearly before you, imitate the system of book-keeping adopted by merchants and manufacturers. Open a separate account for each operation, debiting it with everything that is used or consumed at the market rate, deducting from 10 to 15 per cent. which has been saved by using the material on the spot where it has been produced.

Under such conditions all harmonises, and the true state of things is easily and readily arrived at down to the most trifling details. If you apply these principles, which are the true ones, to the rectification of the Bechelbronn calculations, and substitute the real for the conventional price, all will be changed. Instead of 148*l.* 1s. 8*d.* the cost amounts to 416*l.* 11s. 8*d.* for the production of 710 tons of animal or farmyard manure, raising the price of 1 ton from 4s. 3*d.* to 11s. 9*d.*

Here is some evidence in support of this conclusion ; it is a calculation of extreme simplicity isolated from other farming interests. It shows us that the cost of fattening 800 sheep entails an expenditure of 1,120*l.*, against which you have the sale of the wool and of the animals themselves, realising about 1,000*l.*, that is to say at a loss of 120*l.* As a set-off you have 275 tons of manure, which costs 8s. 10*d.* per ton.

*Cost Price of Sheep Manure on the Farm at Mesnil Saint Miase.**Dr.*

	£	s.	d.
To cost of 800 sheep	784	0	0
300 tons of beetroot pulp	144	0	0
18 tons 1½ cwts. of oil-cake	108	0	0
Colza haulm and reeds	54	0	0
Shepherd and yardman	20	0	0
Interest and commission	10	0	0

Total cost	£1,120	0	0
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Cr.

By wool and sheep	1,000	0	0
275 tons of manure	120	0	0

Total receipts	£1,120	0	0
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Here we have 120*l.* expended for 275 tons of manure; that is, in round numbers, 9*s.* per ton. This is a simple account, and no uncertainty or discussion is possible, not an item undetermined, all is known. We buy the sheep and sell them again, they pay for what they consume, and we find that the value of their manure comes to 9*s.* per ton.

There is one point in this calculation in particular upon which I cannot lay too much stress. We have not given the sheep a litter of cereal straw, but one composed partly of colza haulm and partly of reeds gathered upon the marshes of the Somme, whereby the expenses have been lessened. If we had employed wheat straw for litter, the price of the manure would be raised from 9*s.* to 11*s.* 6*d.*, or say 12*s.* as at Bechelbronn. But perhaps you may imagine that this account is in some parts defective, and that as a rule the production of manure by sheep is less expensive. Well, in order to dispel all doubts upon this point I append below another balance sheet more detailed and more recent than the last, according to which the cost of sheep manure amounts to 20*s.* 10*d.* per ton. This increase in price is due to the depreciation in the price of the wool.

*To Keeping and Feeding a Flock of Sheep from March 1, 1868, to
February 28, 1869.*

Dr.

	£	s.	d.
To purchase of 661 sheep, March 1, 1868	920	13	2
Sheepfold and implements	85	16	8
Distillery pulp, 127 tons 18 cwts., at 6 <i>s.</i> 5 <i>d.</i> per ton	41	10	8
Sugar pulp, 57 tons, at 12 <i>s.</i> 10 <i>d.</i> per ton	36	1	3
Chopped straw, 23 tons, at 1 <i>l.</i> 8 <i>s.</i> per ton	32	4	0
Green fodder (winter), 3,607 bundles, at 3 <i>d.</i> per bundle	45	1	9
„ (summer), 21½ tons, at 12 <i>s.</i> per ton	12	15	0
Carried forward	£1,174	2	6

	£	s.	d.
Brought forward	1,174	2	6
Oats, in the grain, 7 tons 3 cwt., at 8s. per cwt.	57	4	0
Green oats, 550 bundles	8	5	11
White clover (green), 5 tons 6 cwt., at 1l. 12s. per ton	8	9	7
„ „ 46 tons 2 cwt., at 12s. per ton	27	13	4
„ „ (dry), 51 tons 13 cwt., at 1l. 12s. per ton	82	12	10
Meadow hay, 13 tons 3½ cwt., at 2l. per ton	26	6	11
„ „ (second crop), 4 tons 3½ cwt., at 1l. 12s. per ton	6	13	6
Vetch seed	15	13	0
Oil-cake, 12½ tons, at 6l. per ton	75	0	0
Bran, bruised oats, &c., 18 cwt., at 6s. per cwt.	5	8	0
Vetch flour, 5 cwt., at 12s. per cwt.	3	0	0
Spring wheat, 12½ cwt., at 1s. 7d. per cwt.	0	19	9
Dry lucern, 13 tons, at 2l. per ton	26	0	0
Green fodder, 3 tons 6 cwt.	4	12	5
Straw and haulm (various), 88 tons 16½ cwt., at 1l. 8s. per ton	124	7	1
Colza haulm, 10 tons, at 1l. 4s.	12	0	0
Pasture	68	3	2
Food for sheep dogs	10	7	1
Washing and straining	9	7	11
Cartage of manure and soil	20	10	3
Shepherd's board and wages	57	11	6
Tobacco	0	3	0
Purchase of sheep and transport of flock	159	2	2
Purchase of Southdown ram	13	12	3
Interest, at 5 per cent., on 1,006l. 9s. 10d.	50	6	5¾

Being value of sheep and general plant £2,047 12 7¾

Cr.

	£	s.	d.
By manure	114	8	0
Sheep killed for home consumption, 57 stone, at 3s. per stone	8	11	0
Sheep sold	276	9	7
Wool sold	215	13	6
Sheepskins sold	4	7	7
Value of flock March 1, 1869	997	5	10
Value of sheepfolds and implements same date	88	3	3

£1,704 18 9

	£	s.	d.
Expenses	2,047	12	7¾
Receipts	1,704	18	9

Loss £342 13 10¾

A loss of 342l. 13s. 10¾d. on 440 tons of manure produced by the sheep in the course of one year, is equal to an increase in the cost per ton of

Cost of manure per ton, as taken in the account 0 15 7½

0 5 3

True cost of manure per ton £1 0 10½

The quantities and prices in the above account are only approximate, but the sums carried out are exact.

We will now pass from these isolated accounts, taken as examples in order to give greater simplicity to my demonstration, to more general accounts embracing nearly every farming operation.

I shall take my third example from the farm at the Thiergarten (Bas-Rhin), which in 1866 gained the first prize for its eminent owner, M. Schattenmann. In this farm, which we are justified in regarding as a veritable model farm, animal manure cost, in 1866, 20s. 10d. per ton. The expense of producing 551 tons of animal manure and 300 tons of liquid muck estimated as worth 1s. 8d. per ton was 603*l.*, which brings the price of the manure to about 21s. per ton. But what makes this account the more instructive is that in the prize essay the price of animal manure was fixed at 8s. per ton.

Why should it have been fixed at 8s. when in reality it amounts to 21s.? Because M. Schattenmann, notwithstanding his great business capacity, had yielded to the established usage, and separated the account of the manure from that of the animals. The price of the manure was reckoned at 8s. per ton, and the account of the animals was balanced at a loss, whereas the price of the manure should have been estimated by the price of the animals, or should figure as the balance of the account.

On the debit side of the account it is necessary to set down¹—

The cost of the animals.

The interest of capital expended.

The interest on capital sunk in the stables and cost of fodder at its real price.

Expenses of whatever nature.

Serving-men, servants, labourers, veterinary surgeons, &c.

On the credit side place—

The value of the animals at the time the account is balanced.

The animal provisions sold or consumed (estimated at the cost price).

Labour of animals, or their manure, as the balance.

In order to increase the price of manure at the Thiergarten from 8s. to 20s. 10d., it is only necessary to add the first cost of the manure to that of the animals, and group the items as I have just done.

The course I pursued was recognised by M. Schattenmann as a legitimate method of rectification; in fact, the light

¹ For the details of this account see Part I., p. 64.

thrown upon the comparative actions of animal and chemical manures, by the experiments we conducted in concert at the Thiergarten, induced him to become one of the firmest supporters of the new doctrine. Try for your own sakes to procure trustworthy documentary evidence relating to this great question of manures, and you will find that in the great majority of cases the cost exceeds 16s. per ton, and you may conclude that those who maintain the average price to be less have only employed an arbitrary valuation. It only remains for me to show how you ought to proceed in order to fix the value of the work done by the animals, and to estimate the difference in the economy of keeping stock, for the sake of their meat or wool, instead of beasts of burden. As soon as we have fixed the real value of the food consumed, nothing is easier than to fix the value of animals like cows, sheep and pigs. On the one side we put the expenditure, on the other the receipts, the cost of the manure going to the credit account, being, in fact, taken as a set-off against the deficiency the account always discloses.

In the case of beasts of burden we have two unknown questions to solve—viz., the price of labour and the price of the manure. If we separate the one it is to the prejudice of the other. But how are we to give the exact value to each? Take horses, for example. Why do we have horses upon a farm? What is their chief use? To prepare the soil, carry the crops, and perform other work inseparable from farm labour, that is to say, to supply “power”. Power being their principal product, and the reason of their presence on the farm, the balance may be struck as follows:—

Dr.

The value of the animals.
The interest on capital and working fund.
Charges of all kinds.

Cr.

The value of the animals after deducting the sinking fund.
The manure estimated at its real value.
As payment; the work estimated at ten hours per day.

If we subtract the labour from the credit side, the account shows a loss. To obtain exact returns it is necessary, then, to have regard to the labour, and make that a set-off against the loss. This mode of procedure is so conformable to the rules followed in all trades and manufactures, that you will hardly believe they have not yet been applied to agriculture. Two principal causes, however, account for this—the one altogether a moral one, if I may so express it,

and the other is more specially due to an absence of sufficient intelligence to define everything in farming. The moral cause is connected with the exterior conditions under which farming is carried on. Nothing can be concealed. Every one acts under the eye of his neighbour, and no one is willing to admit that he does wrong; add to this fact the dominant idea that there can be no good farming without farmyard manure, and you will have a full explanation of the universal tendency to hide the real cost of manure. I will refer to an account, admirably kept, but those who can see beyond the surface will detect this fatal tendency in each item.

We find that the manure produced in stables comes to about 6s. 4d. per ton. This information was obtained from a manufacturer who became a farmer, and who, after having made a large fortune by commerce, was unwilling to confess that stable manure was very dear, because every one around him insisted that it was the cheapest of all manures.

*Horse Account.*¹

Dr.

Expenses from March 1, 1868, to February 28, 1869 :—

	£	s.	d.
To value of 19 horses on March 1, 1868	324	0	0
Stables and implements	87	4	0
Oats in grain, 23 tons 2 cwts., at 8 <i>l.</i> per ton	184	16	0
Rye	0	12	10
Wheat	1	4	0
Meal (various), 2 tons 1½ cwts., at 12 <i>l.</i> per ton	24	18	0
Chaff and bruised grain, 16 cwts., at 6 <i>s.</i> per cwt.	4	16	0
Carrots, 5 tons 6½ cwts., at 1 <i>l.</i> 4 <i>s.</i> per ton	6	7	10
Chopped straw, 2 tons 12 cwts., at 1 <i>l.</i> 8 <i>s.</i> per ton	3	13	0
Meadow hay, 43 tons 8 cwts., at 2 <i>l.</i> per ton	86	16	0
Lucern, 9 tons 7 cwts., at 2 <i>l.</i> per ton	18	14	0
Green clover, 7 tons, at 12 <i>s.</i> per ton	4	4	0
Straw (various), 46 tons 5 cwts., 1 <i>l.</i> 8 <i>s.</i> per ton	64	15	0
Colza haulm, 2 tons, at 1 <i>l.</i> 4 <i>s.</i> per ton	2	8	0
Pasture	4	18	0
Tobacco	0	3	0
Advertising the stallion "Houp là"	0	3	10
Carters' food and wages	112	12	0
Extra carter	10	19	6
Repairs of carts, shoeing, veterinary surgeon, lighting, &c.	77	0	0
Interest, at 5 per cent., on 411 <i>l.</i> 4 <i>s.</i> value of horses and plant	20	11	3
Total	£1,040	16	3

¹The quantities and prices in this balance sheet are only approximate, but the figures carried out are exact.

Cr.

Receipts from March 1, 1868, to February 28, 1869:—

	£	s.	d.
By manure, 186 tons, at 5s. 3d. per ton	48	16	6
3,676½ days' work, at 3s. 2½d. per day	589	15	5½
Proceeds of the sale of the mare "Duchess"	17	0	0
Horses dead or slaughtered	1	16	0
Fees for stallion "Houp lã"	5	16	0
Extra work by carters	3	16	11
Value of horses, March 1, 1869	272	0	0
Stables and plant	86	10	2
	<hr/>		
	£1,025	11	0½

	£	s.	d.
Expenses	1,040	16	3
Receipts	1,025	11	0½
	<hr/>		
	£15	5	2½

The loss of 15l. 5s. 2½d. divided over 186 tons of manure, produced during one year, gives an increase per ton of	0	1	7¾
Price as above	0	5	3
	<hr/>		
Real price of horse manure per ton	0	6	10¾

This table shows that the manure costs 6s. 10¾d. per ton. But in this case we estimate the labour of a horse for one day at 3s. 2d., the account ought, however, to show that the real cost of the manure is 10s., the horse's day being put down at 2s. 10d. We therefore put the whole down thus:—

Cost.

	£	s.	d.
Value of the animals	324	0	0
Stable fittings	87	4	0
Cost of keep	408	16	5
Cost of repairs	77	0	0
Carters' wages	123	11	6
Interest on capital	20	11	3
	<hr/>		
Total	£1,041	3	2

Receipts.

	£	s.	d.
Value of animals	272	0	0
Fittings	86	10	2
Sale of the mare "Duchess"	17	0	0
Serving 10 mares	5	16	0
Carters' work	3	16	10
Three horses slaughtered, at 12s.	1	16	0
186 tons of manure, at 9s. 7d.	89	2	6
3,676½ days' work, at 3s. 1d. to balance	566	15	10½
	<hr/>		
Total	£1,042	17	4½

I have fixed the price of the manure at 10s. per ton, because this price, which is its real cost, fixes the cost of the labour done by the horses as beasts of burden.

I do not insist upon the accounts of the animals kept for fattening, their economy being conformable to principles that I have already admitted.¹

¹ In the report that I prepared in 1868 of the results obtained, on a large scale, by means of chemical manures, I estimated the price of labour and manure of beasts of burden—separating the production of manure from the production of force. Notwithstanding the certainty of the principles upon which these calculations were founded—the justice of which you will admit—and taking into consideration the time when we shall employ steam ploughs more largely, I prefer the system that I have just demonstrated. The truth compels me to add, and I hasten to remember it, that I have been greatly influenced by the opinion of a gentleman, as honourable as he is distinguished, whose name marks an era in the history of chemical manures—I mean M. L. Couvreur, the founder of the first chemical manure manufactory established in France, and in which the manure was made according to my formulæ. M. Couvreur has been brought in contact with agriculturists of all ranks and conditions, and in this way he was enabled to form sound opinions upon these serious and difficult agricultural questions. It seems to me that no one can read, save with a lively interest, the following observations, which he sent me on February 3, 1869:—

“The question to which you call my attention has occupied me more than any other since I have been brought into contact with the agricultural world, and in the absence of any communication from you, I should have followed, with the greatest interest, the truthful considerations and lucid calculations that you have put forth respecting the question of manure. I have, in fact, been often struck by the defective manner in which I think this question has been treated by agriculturists.

“I do not know if I am wrong, but it appears to me that in many cases that part of the working of a farm which relates to the production of animal manures is one of the most important in farming operations; but above all, I do not find in any books that I light upon, any mention of such charges as house expenses, taxes, life and fire insurance, nor clerk's work; in a word, no one appears to keep an account either of general expenses or of risks. A cow bought to produce manure injures a labourer, whom it is necessary to pension, but where is the agriculturist who would place this expense under the heading of manure? although it would be strictly logical to do so.

“When we wish seriously to set about this calculation, it is necessary to take account of the whole of the expenses concerned, and after having marked, on the one hand, those that are particularly connected with the production of manure, make a proportionate and reasonable division of the remaining expenses, which are generally lumped together under the title of general charges.

“But to put down, as is generally done, so much for keep, so much for litter, so much for the purchase of animals, and interest, &c. &c., is to fall short of the truth. Yet people remain quite satisfied with such results, and are consequently the victims of a most complete illusion. You see by this how much I approve the successful efforts that you are making to throw light upon this question. Your ideas upon the value to be attached to the fodder consumed on the farm, the separation between the

If I have succeeded in giving proper expression to my thoughts, our common conclusion will be that in the great

intrinsic value of manure and its cost, are most reasonable; but you will perceive from the reflections that I have just submitted to you, that I urge still greater care in the reforms applicable to this branch of agriculture, and that I go even so far as to put to the account of manure a just proportion of the expenses of management, and further that I hold there can scarcely be any exaggeration in this.

"In fact, when I think of all this trouble of keeping live stock, such as cows, sheep and pigs, and of the worry they bring, the risk they are subject to, the space they take up; of the connection to be made for the sale of milk, butter, cheese, wool and meat; of the distance it is necessary to travel in order to buy, to sell and to maintain the proper number of stock throughout the year; I would ask whether this is not the chief occupation of the live-stock breeder, and whether he ought not to profit by the fruits of his labours. What could be said of a colliery proprietor who, after establishing a forge to utilise his coal, would divide the price of the sale of iron by the quantity of bushels of coal consumed, and would give the quotient as the amount gained by the coal expended, keeping silent about the general expenses of the forge and his own personal labour? This would be an exact counterpart of the method employed in calculating the cost of manure.

"I am happy to find that I agree so well with you on the general solution of the question, and I ask your permission to make a few observations upon one point in particular. It is relative to the cost of manure produced by beasts of burden. I think with you that we ought not to carry to the credit side the rate per day of the work done, calculated from the wages of the labourer, but I do not think that the holidays and days of rest can legitimately be charged to the manure account, for that would be burdening it with the cost of matters which ought not to be put to its charge.

"When too many horses are bought for the amount of work to be done, when horses hurt themselves and remain in the stable, or when they are made to produce more than the normal amount of work, these are the kind of circumstances which ought not to be reckoned in the price of manure.

"Besides, in my opinion, the reckoning of draught horses is no more able to regulate the cost price of manure than is the manufacture of gas to give the cost price of the coke that remains from it; to do so would be taking the accessory for the principal. The calculation to be made in order to discover the value of the work done by the horses will not be obtained by the price of the manure, which is only one of the elements. The account being debited with all the expenses that appertain to this branch of service, will have to be credited with the manure, being one of the products that arise therefrom, that is, its intrinsic value, according to the definition that you have given as to the base of the calculations.

"Then the remaining balance on the debit side will be divided by the number of days' work, by which means the cost price will be arrived at.

"If this result estimates the day's work at a higher price than can be obtained for the day labourer, the difference must be added to the arbitrary price of the manure; since it is in consideration of the manure that this increase of expenditure has been incurred. In every other case the account of the beasts of burden is not able to furnish any base from which to obtain the cost price of the manure. Such are the reflections that, in response to the great confidence that you place in me, I venture

majority of cases animal manure costs more than it is worth.

A last argument, which cannot be left without reply, is the following: It has been said that in rural experiments manure becomes a heavy item in the expenditure, but in the great centres of population—Paris, Lyons and Marseilles—it can be procured in abundance at a greatly reduced price. Doubtless if a gardener acts with discretion it is possible for him to obtain a few cartloads of manure at a cheap rate. But when operations are conducted upon a large scale, the conditions are altered.

How much then does manure cost? M. Dailley, the director of the Paris General Omnibus Company, as well as of a large carrying agency, and who was consequently in a good position to solve this question, has estimated the price of stable manure delivered at Trappes, near Versailles, at 10s. 7d. Here is the account:—

1 ton of manure at Paris	s. d.
Loading, 4d.	6 3
Cartage to the Batignolle, 1s. 7d. }	2 3
Loading, 4d.	
Railway charges from Batignolle to Trappes	1 10
Loading	0 3
	<hr/>
	10 7

This is without reckoning the necessary expenses incurred in carrying it from the railway station at which it arrives to the farm where it will again have to be unloaded, and lastly spread over the soil.

What becomes of the flattering declarations made by the advocates of stable manure in face of this incontrovertible evidence?

The conclusion we arrive at is that the cost price of manure rightly reckoned is rather above than below 16s. But this is not all, for in order to estimate exactly the cost of manure it is necessary to notice the last item of expenditure, viz., the inseparable cost attached to handling large quantities.

A civil engineer of great merit, M. Caillet, the proprietor of an important experimental field in Normandy, fixes the accessory cost, inseparable from the production of

to submit to you. I hardly like to say that I will add more verbally when you wish me to do so, but the fact is you have no need of me, or of any one else. Your mind, where order and method have such a prominent place, must necessarily have complete intuition in questions of this kind.

“L. COUVREUR.”

stable manure, at about 1s. 5*d.* per ton. He calculates it thus:—

	<i>s.</i>	<i>d.</i>
Cleaning and washing the stable	0	5
Loading and cartage by one man and the farm horses	0	11
Spreading the manure	0	1
	<hr/>	
	1	5

This puts the cost of one manuring of 50 tons at 3*l.* 12*s.* 10*d.*, a result that sufficiently explains itself when we know that the manure contains 80 per cent. of moisture which must be carried, spread and manipulated at a pure loss, for the moisture adds nothing to the efficiency of the active part. You see that when we go to the root of the matter the question of animal manure, in a very short time, appears in quite a new light, and it is impossible to maintain that it is more economical than chemical manure.

If there is an agriculturist for whom I entertain respect and consideration, it is assuredly Mathieu de Dombasle. Following the popular notion that farming was impossible without animal manure, Mathieu de Dombasle computed the cost of feeding his stock at a reduced price. The consequence of this system was inevitable. The manure appeared to cost from 4*s.* to 4*s.* 9*d.* per ton. The result of this error in calculation, the failure of this eminent man's career, and the impossibility of discovering the real cause of the slender crops at Roville, notwithstanding all his efforts and his care, have already been referred to. But for this mistake he would have obtained a veritable triumph instead of a nobly confessed failure, and he would have inevitably discovered the new principles on which agriculture is at present carried on. But, following the ideas of his day that the formula—meadow, cattle, cereals—made fruitful by the rotation of crops, and believing that such was the end of agriculture, Mathieu de Dombasle had only one fixed idea, and that was to obtain manure at the lowest price. He reckoned the cost of dry fodder for the stable at 26*s.* per ton; then he reckoned that he was able afterwards to sell it at from 40*s.* to 48*s.* The manure account was of the simplest nature. Add to the price of the straw, estimated at 24*s.* per ton, the cartage per ton of the manure, say 2*s.* 1*d.*, this amount, expressing the value of animal excreta, being carried to the credit of the live stock account.

This system represented the price of the manure at 5*s.* 3*d.* per ton. Later on Mathieu de Dombasle began to see that this method of calculating was faulty, but, unfortunately,

he perceived his error too late, for he would have had to change his entire system of farming. The farm at Roville consisted of high and low lands. To transport the manure to the hilly parts during the winter months entailed great expense in the matter of carriage. This was a considerable difficulty in the working of the farm.

Mathieu de Dombasle, who found that it would answer his purpose better to concentrate his manure within a circumscribed space, resolved to employ artificial manure upon the upland and to reserve his animal manure for the lowland, but as he had fixed the price of his manure at 5s. 3d. per ton, the cost of manuring amounted to 1l. 4s. per acre. He consequently bought a quantity of wool waste at the same rate per acre, but the effect was hardly equal to that of animal manure. Suppose, however, that instead of fixing the price at 1l. 4s. per acre he had taken 2l. 8s. per acre, which was the real price of the animal manure. Under these new conditions the crops would have certainly been better than with animal manure, and he would at the same time have perceived two things:—

(1) That animal manure, as a rule, is very expensive.

(2) That it is often more advantageous to bring chemical manure from a distance than to produce animal manure.

If he had substituted desiccated blood or powdered hoof for the woollen waste, the decomposition of which is a slow process, the manure, acting by its nitrogen, would have produced a yield of wheat at the rate of 33 bushels per acre instead of the 16½ bushels; and instead of a great loss the accounts would show a profit of 3l. 4s. per acre, and his success would have been complete. A faulty calculation sufficed to snatch from this man the only recompense that he desired—that of serving his country by improving the condition of the labouring agricultural classes.

The cause of this immense deception was the old school formula, that there is no good farming without animal manure.

You see by this instructive example how important it is to banish fictitious calculations. There is only one way to obtain lasting success, and that is to estimate each article at its real cost. To speak truly, it is necessary to look upon the cattle lairs and the stables—the equivalent of annexed farm industry—as being a manufactory connected with the farm, and to make these cover the cost of what they consume, and also to put the manure at its full price.

If the animal manure does not cost more than 10s. per ton, well and good, but if the price reaches to 12s. or 16s. its use

must be restricted, and chemical manure must be used. But whatever course is taken, it is necessary that agricultural products should be estimated at their real price, whether they are carried to market or consumed on the farm, and that, convinced that no profit can be derived except by using a plentiful amount of manure, the farmer must seek his manures where they are cheapest. If I get no credit for anything else, I hope to do so for being frank and outspoken.

The question of accounts being settled by what precedes, we will now pass on to other considerations. Let us stop at this new question, no less important than the first: Which is the most efficacious, farm or chemical manure? Which has the decided advantage? The following is the result of more than 2,000 experiments made by various farmers. I take wheat for the first example. In 138 trials the chemical manure carried the day on account of the larger yields and the superiority of its results in a given time.

18 cwts. 1 qr. of chemical manure produced $32\frac{3}{4}$ bushels, while 40 tons 4 cwts. of farm manure only produced 23 bushels.

In round numbers this is an excess of over 9 bushels per acre in favour of the chemical manure. But this is not all. If these 138 results are analysed in order to ascertain the exact differences between the crop obtained with chemical and that with animal manure, we obtain these two parallel series:—

Times	Per acre	
	Chemical	Stable
	Bushels	Bushels
10	51	43
22	$39\frac{1}{2}$	$29\frac{1}{2}$
20	$34\frac{1}{4}$	$21\frac{1}{4}$
22	30	16
26	$24\frac{3}{4}$	16
38	$16\frac{1}{2}$	$13\frac{1}{4}$

The following gives us the result of four different growths:—

Times	Per acre	
	Chemical	Stable
2	Bushels 38 $\frac{3}{4}$	Bushels 27 $\frac{1}{2}$
1	24 $\frac{3}{4}$	16
1	16	13 $\frac{1}{2}$

With the chemical manure you see there were two very good harvests—one fairly good, and one rather poor; with the farmyard manure, two fair and two rather poor results.

Beetroot.—Experiments to the number of 190 led to the same conclusions with beetroot as with wheat; but the chemical manure excelled the farmyard manure in no less proportion. Half a ton of chemical manure produced 20 tons 16 cwts. of beetroot per acre, whilst 20 tons 5 cwts. of farmyard manure only produced 16 tons 14 cwts. of beetroot, which gives an excess in favour of the chemical manure of 4 tons 2 cwts.

The distribution of crops is not less significant than the contrast of the average yields.

Times	Per acre			
	Chemical		Farmyard	
	Tons	Cwts.	Tons	Cwts.
8	36	8	28	1
31	25	8	19	19
35	21	9 $\frac{1}{4}$	17	9
61	17	9	13	18
40	14	3	11	11
25	9	15	9	6

What adds singularly to the importance of these results is that with the chemical manure beetroot contained 20 per cent. more sugar than with the farmyard manure.

Potatoes.—The same effects were observed as with wheat and beetroot. In 83 experiments we obtained:—

Times	Per acre			
	Chemical		Farmyard	
	Tons	Cwts.	Tons	Cwts.
17	15	7	12	6
16	9	14	6	14
26	6	18	5	19
24	4	9	4	13

The following shows the average :—

	Per acre	
	Tons	Cwts.
8 cwts. of chemical manure produced . . .	9	1
15 tons 19½ cwts. of farmyard manure produced . . .	7	8
Balance in favour of the chemical . . .	1	13

Oats.—The same superiority of the chemical manure is manifested in the case of oats, 28 comparative experiments giving :—

	Per acre	
	Tons	Cwts.
7½ cwts. of chemical manure produced . . .	47	
20 tons 4½ cwts. of farmyard manure produced . . .	39	
Au average excess in favour of chemical . . .	8	

Barley.—Similar results were obtained with this cereal.

	Per acre	
	Tons	Cwts.
9½ cwts. of chemical manure produced . . .	35½	
16 tons 7½ cwts. of farmyard manure produced . . .	28	
Excess in favour of chemical . . .	7½	

Maize.—The same results were obtained with maize.

	Per acre	
	Tons	Cwts.
7½ cwts. of chemical manure produced . . .	41½	
17 tons 4 cwts. of farmyard manure produced . . .	31	
Excess in favour of chemical . . .	10½	

Its effects were not less satisfactory or striking upon rye, buckwheat, flax, hemp and grass.

Number of Experiments		Result per acre	
		Chemical	Farmyard
		Bushels	Bushels
3	Rye	37½	—
2	Buckwheat	33½	21
4	Colza	30½	22
1	Flax	2 tons 16 cwts.	1 ton 14 cwts.

Instead of averages which it is often difficult to verify, perhaps you would prefer less general profits. Here is the result of 34 experiments upon beetroot made by order of the Minister of Agriculture in the farming schools :—

Beetroot.

	Per acre	
	Tons	Cwts.
10 cwts. of chemical manure produced	15	12
22 tons 16 cwts. of farmyard manure produced	13	12
Without any manure	9	12

The same conclusion was come to at the Institute at Grignon :—

Beetroot.

	Per acre	
	Tons	Cwts.
10 cwts. of chemical manure produced	20	0
22 tons 16 cwts. of farmyard manure produced	17½	1
Chemical manure	26	8
Large doses of farmyard manure	25	4

Since 1868 I have collected more than three thousand new facts, the results of which are conformable to the preceding.

Was ever a system presented that had so many favourable guarantees? However, this is not all. In the domain of isolated experiments I may quote more decisive experiments made in the farming school of Beyne, in the Landes, under the superintendence of M. Dupeyrat. The exceptionable value of this experiment is due to two causes: first, its long duration, for it was continued for more than six years, and, secondly, on account of the doubtful, not to say hostile, spirit in which it was conceived. Pinning his faith more closely to the precepts of bygone days than to argument, M. Dupeyrat wished to prove from experiment that farmyard manure excelled chemical manures in power, duration and in profit; and that the union of stable manure

with green and chemical manures ought to excel in its turn every other combination.

What has been the result of his trial, inspired, as I have said, by the tacit hope of proving the falsity of the new doctrine? Its most peremptory and decisive vindication on all points! With respect to the amount of the crops, the profit realised, and the improvement of the soil, the chemical manure alone came out triumphantly from the trial. I need not enumerate in detail all the results obtained; it would be only recapitulating what you already know. I will, however, make an exception in one instance, viz., the more lasting effects of chemical manure as compared with stable manure. After three consecutive years' growth, during which the chemical manure had shown itself much superior, maize was cultivated for a fresh period of three years without the aid of any manure. And on the plot of ground which had originally been treated with chemical manure the increased standard of results was maintained.

Land originally manured	Crop per acre in three years ¹		
	Total weight of the crop		Bushels of grain
	Tons	Cwts.	
With chemical manure	7	12	72½
Half chemical and half farmyard	6	16	64
Stable alone	6	0	58
Ground never manured	4	16	50½

These results are, however, rather lower than was actually the case.

The price of 11s. 2d. fixed for stable manure is the result of an arbitrary estimate, and is consequently under the mark. At the farm at Beyne the cost of agricultural implements and

¹ The *Journal d'Agriculture*, May 2, 1874, p. 171, says:—

“After seven years of consecutive experiments M. Dupeyrat concludes:—

“1. That chemical manure had had an action at least equal, and often superior, to that of stable manure on the yield.

“2. Reckoning chemical manures at their market value, and stable manure at 11s. 2d. a ton, the annual expense of manuring was nearly the same per acre; the use of chemical manures produced a far higher net profit than that obtained from farmyard manure.

“3. The good effect of chemical manures is prolonged beyond the first year, and in comparing the lasting effects of chemical and farmyard manures the advantage is gained by the former.”

materials, the cost of stabling, the interest on the capital invested in the stabling, were all included in the general expenses instead of being placed altogether under the heading of the animals themselves, and this reduced the price 4s. or 5s. per ton. The object we must have before our eyes, and the obligation that it is necessary to satisfy, is not to make manure, always and everywhere and with no regard to price, but simply to work into the soil the manure necessary in order to obtain a good crop. If you lack stable manure, bring in chemical manure from outside. Manures made in factories are, as a rule, more economical than farmyard manure. I have been misrepresented and my declarations travestied, but they have never been refuted; the science of agriculture is coming to light in its entirety. This revolution, which is beginning to prevail, will be accomplished because our interest makes it binding upon us, and because reason, science and facts prove its legitimacy. By the new method the interest of the public is satisfied in the same degree as that of private individuals. To the nation living is procured at a cheap rate, to the farmer a profit hitherto unknown.

Progress and preservation, order and liberty, the union of all the productive forces of the country—this is the aim and that is the result.

Let us consider the economical conditions which ought to be realised by the country, and investigate, under all its aspects, this new part of our subject.

And, first, what is the true situation of our agriculture? You know it is not good. The country does now draw from the native richness of the soil and the mildness of the climate all the advantages that it might obtain. The peasantry of France are ill-fed and ignorant in the extreme. Instruction is quite inadequate, and their moral sense with respect to the most sacred things in life, family relations, is singularly blunted.

Those who consider that I was not animated by a proper national spirit and love for my country I would advise to follow my example, and to examine for themselves, without prejudice, the conditions of the inhabitants of our villages and hamlets. But that is not the point I wish to impress upon you. The study of moral causes is remote from my subject, which is the laws of production. I will return, therefore; I have said, and I again repeat, at the risk of being wearisome, that to obtain good results it is necessary to manure the soil well.

The question, therefore, upon which I take my stand is this: In France shall we be able to manure the soil well

when working only with animal manure? No: and why? Because it is too much divided. The parcelling out of land, which it is necessary not to confound with division of property, has become one of the greatest evils of the present day.

It is to this that we owe the depopulation in the country parts; this state of division paralyses us! To you who may be inclined to doubt I give the following cruel realities.

Statistics show that the cultivated land in France amounts to 115 millions of acres; of this number 65 millions belong to large estates, and 50 millions to small and medium landowners. So far nothing much appears the matter, but this 115 millions of cultivated acres is redivided into 143 millions of plots according to the Government Survey, and held by 14 millions of ground landlords.

This would represent each plot as five-sixths of an acre. But from this division, to be exact, we must subtract 65 millions belonging to large estates; the plots, we find, are reduced to five-sixteenths of an acre, of which ten are grouped under one ownership. Under such conditions with these aliens dispersed over the whole country what can be done? Listen to the inexorable declarations of statistics. Of the 14 millions of plots there are 7 millions underlet at 4s., 2 millions at from 4s. to 8s., and 2 millions at from 8s. to 16s.

Consequently 3 millions of landowners receive no rent, and are so far in a state of indigence.

But let us restrain our feelings and look to the root of the matter. What can the system of agriculture be worth which parcels out farms in quantities of $\frac{1}{2}$ or $\frac{1}{4}$ of an acre each? Strictly speaking, none; the time which is lost in going from one to the other triples the expenses.

Their smallness prevents the use of animal labour, which is fifteen times less costly than man's labour. Enclosed the one in the other, these plots of land are cultivated with difficulty, we are obliged to increase the number of roads and vacant spaces on account of their unfortunate position. When property is divided in this way, it is not only loaded with general expenses, but it is impossible to produce manure; they must cultivate without it, and the continuation of this devastating system will undermine native fertility, and by an inevitable reaction the public prosperity will suffer. This is so true that the mean yields of wheat in France in the departments of the North are $15\frac{1}{2}$ bushels per acre, and in the other at most from 9 to 11 bushels. Under such conditions what will be the ultimate price of a bushel of wheat? Is it not a state of things that must be altered? The Ger-

mans, formerly placed under the same conditions as ourselves, have succeeded in freeing themselves from them, with some hesitation at first, for the rural populations began by resisting, but now they are carrying out the change with boldness, unanimity and decision, which must radically change the condition of existence in that country. In all parts of Germany they have, during the last two centuries, made a complete territorial liquidation; they have joined by exchange their outlying plots, done away with the roads, and converted straggling and barren lands into compact and profitable holdings.

Do you wish to know the result of this enterprise which has been so favourable to the entire nation and also to the interests of each?

I am able to give you an example, for which I am indebted to M. Tisserand, Inspector-General of Agriculture, who has seen and inspected what he relates.

"The land belonging to the Commune of Hohenhaida (Saxony)," he says, "consisted of $1,472\frac{1}{2}$ acres belonging to 35 owners. These were again divided into 774 small plots of about $1\frac{1}{2}$ acres each, the redistribution reduced the number to 60 of a superficial area of $24\frac{1}{2}$ acres traversed for the most part by a single road. This work was executed in one year at a cost of 125*l.* 1*s.* 3*d.*, that is, 4*s.* 2*d.* per acre. By the enclosure of surface formerly taken up by roads and hedges, they gained $24\frac{1}{2}$ acres, that is to say, more than the expense of the territorial union: the consequence of the redivision has been the necessity of enlarging all the barns and granaries in order to store the increased crops.

Expense	.	.	.	.	.	.	125 <i>l.</i> 14 <i>s.</i> 3 <i>d.</i>
Surface gained	.	.	.	.	.	.	24 $\frac{1}{2}$ acres"

I know well that in France whoever proposed a reform of this nature would encounter the most strenuous opposition.

The law of property which came to us from the last Revolution is of such a nature, and has excited certain false ideas with regard to the possession of the soil, that almost insurmountable obstacles must be overcome in order to arrive at a satisfactory result. But it is for you and me and all of us to make the people understand that when the land is divided to excess not only is cultivation impossible, but if the land is not manured the interest of all is endangered; that when the soil is divided beyond a certain point the cultivator will be unable to obtain any profit; that not being able to help himself with horses he will become a slave of the soil, and the property which ought to emancipate him

becomes the instrument of his servitude. It is necessary that we who have the knowledge of these facts should convey them to the poor who live by the sweat of their brow, feeling confident of their final success. Let us follow this up, firmly persuaded that upon its solid base we can build up a new social constitution.

Suppose, for an instant, and as a simple hypothesis, that in place of the 50 or 60 millions of acres represented by 14 millions of small holdings dispersed amongst 10 millions of people, half of whom are almost in a state of poverty, this vast tract of land were to be divided into small farms of 15 to 25 acres, what a change would be produced in the economy and moral conditions of the country! Production, family relations, the increase of population, education, morality, would be all changed, and the France of to-day, wounded, beaten down and divided as she has been, would return to her bold attitude and follow the glorious course of her destiny, and as a sign of the triumph of right over might she would renew her chivalrous traditions of honour and generosity. Do you know that since 1826 the country has not produced enough for our own subsistence? Divide this period of 46 years into 4 parts, and calculate the deficit for each portion, and you will find that the increase is hardly credible—

	£
1827 to 1836	920,000
1832 to 1846	1,040,000
1847 to 1856	3,040,000
1866 to 1868	8,960,000 ¹

We must not lose sight of the fact that I restrict this deficit to the most essential agricultural commodities, for if we go beyond that it would include wool and wood for building, and the deficit would then reach 20 millions sterling. This is affirmed by M. Pouyer-Quertier. The interest at 5 per cent. on 10,000,000*l.* only would be 500,000*l.* It may be said that for a country like France a deficit of 10 or even 20 millions is a matter of secondary importance. Were this deficit only a passing one, we might look on it as unimportant; but seeing that it is continuous and increasing, we cannot afford to ignore it. It shows a gradual weakening of the resources of the people, and its gravity is confirmed by the lessening in the rate of increase in the population. While neighbouring nations double their population in 50 or 60 years, France takes 130 years. At the beginning of the

¹ For further details see my lecture on the increase in the price of provisions, in the *Journal Officiel* of March 7, 1870.

century we were one of the first nations in Europe with respect to population, but we are now only in the third or fourth rank. The question is really one of figures and admits of no discussion.

For six years past I have unceasingly drawn the attention of the ruling powers of the nation to this evil, and have warned them that the true riches of a country are to be found in its population. There is an intimate relation between the productive power of a State and the increase of its inhabitants, but of our ninety departments there are thirty-five where the population is decreasing. The nations by which we are surrounded are on the other hand increasing steadily, and we shall ultimately be borne down by numbers if a speedy remedy is not adopted.

Putting aside all such considerations for the present, let us return once more to the practical side of the question. The system of cutting up the land into microscopic holdings, the legacy duty, and other charges on the transfer of property to a man's heirs, are so heavy that they often exceed the value of the legacy itself.

In the case of holdings worth less than 20*l.* the legacy duty, &c., will often amount to 123 per cent. on the value of the property. The effect of this on a country which is broken up into small holdings can readily be imagined. Before the war the duty payable upon the transfer of property, by sale, legacy or exchange, was only 6 per cent. At present it is 10 per cent. on three years' rent. Again, the difficulties of raising money on farming stock are very great. A farmer, for instance, who holds stock worth from 4,000*l.* upwards cannot raise a few hundreds in case of necessity, for the law steps in and forbids anything being done which may lessen the guarantee possessed by the head landlord for the payment of his rent, not only in the past and present, but in the future also. The same custom obtains with regard to standing or coming crops.

The Government is too busy with other questions to be able to notice these facts, but we who have the most intimate knowledge of them can work great good by enlightening public opinion on these vital questions.

LECTURE XIII.

LIVE STOCK—THEIR COMPOSITION—RULES FOR FEEDING.

I NOW come to the culminating point of the agricultural question, viz., Cattle, with which the work of transformation that agriculture pursues and should accomplish ceases.

What has not been said, and further what have I not been made to say, respecting cattle and animal manure? So much that it has not appeared to me of any use to reply, so I have left people to talk. It is necessary to allow time for such questions to be considered and affirmed.

Now that the doctrine of chemical manures is admitted everywhere in France, as well as abroad, meeting only with the lowest form of opposition, small personal grudges, the moment for explanation is come. We will speak therefore of cattle.

I take up the question at the point where I left off last year when replying to the gallant captain who became a farmer, and who requested me to give him instructions how to succeed. I said, "Fill your barns with hay and straw, manure your grass lands with chemical manure, and when you have plenty of fodder then the time will have come for you to think of cattle".

We will add to this advice a few declarations of principles, in order to prevent equivocation and defy evil interpretation.

Are cattle indispensable to good agriculture? No. Since the introduction of chemical manure animal manure has irretrievably lost the character given to it in the past of being the exclusive means of fertilisation.

Without animal manure is the soil liable to lose any part of its inherent properties? No; for chemical manures will give to the land more than the crops take from it.

Is it true that the agriculturist who possesses an equal surface of pasture and arable land is certain of profit? No; this system gives neither profit nor security, for it weakens the soil. These ensuing declarations necessitate another on my part of a very different kind, but which is not the

less necessary if I would remain faithful to those habits of sincerity from which I have never swerved. I have never given much attention to the subject of cattle. When I speak of the growth of plants, of the rotation of crops, of manure, or of analysis of the soil, I speak always of my own personal experience, which I am able to guarantee. With respect to cattle my position is widely different. I have never made any experiments on the subject, and practically it is not in my province.

However, led away by the force of circumstances, I have for many years inquired into the most trustworthy researches on the subject of cattle; I wished to know the results of experiments made and published abroad, and in proportion as the facts have become familiar to me, considerable light has been thrown upon my mind. I have found to my great surprise that the laws which preside over the formation of animal substances are the same as those which preside over the formation of plants, and that the economical conditions which render culture remunerative apply equally to the raising of cattle. The beings on which we work are different; the substances which serve for their production are also different; but I repeat that the laws which regulate the increase of plants and animals are the same. When I attempted for the first time to define the cause and effect of so complex a work as vegetation, I took as a term of comparison the formation of such minerals as are subject to the most simple phenomena, basing my ideas as much upon contrasts as analogy, in order to determine the play of those numerous phenomena of which vegetation is the result.

I shall at the present time follow the same plan. Knowing how plants are born, how they live and die, I shall utilise them as a test to define by the aid of a perpetual parallel the conditions that preside over the formation of animal substance.

But allow me to repeat again that although, with respect to vegetation, theory and practice with me go hand-in-hand, and mutually support each other, still, with regard to cattle, I am simply a theorist. Having eased my mind by this declaration I shall no longer hesitate to give you the first attempt at synthesis which appears to me to trace back to common laws the raising of cattle and the production of vegetables.

We will first consider animal matter in relation to its organisation and production.

The number of known animals is much greater than

that of plants. If we take the infusoria and microscopic species into account they may be enumerated by hundreds of thousands, but in any case we must bring the same method to bear upon animals that we have upon plants. Analyse and isolate the elements of which they are composed under the most varied forms, and you will find that the unity of substance is expressed by fourteen invariable ever-present elements, which are, moreover, precisely the same as those contained in plants, so that they spring from a common source. The relations according to which these elements are associated in the two kingdoms change, it is true; but their intrinsic nature remains the same. You know that between plants which have arrived at the limit of their evolutive perfection and the substances which have served for their production there are two remarkable series of products, not completely organised, but on the way to become so. The object of these transition products is principally to serve as a way for the organisation of tissues, and they may be called the physiological elements of plant life. Chemists call them the proximate principles: they form two distinct series—carbohydrates and albuminous matters.

It is a remarkable and unlooked-for circumstance that these same proximate principles exist in animals.

Let us push the parallel still further. Analyse the active principles common to plants and to animals, and you will find the same properties and the same composition.

There is no appreciable difference; the identity is complete—the starch, albumen, glucose and fibrin of animal or vegetable origin are so closely analogous as to be easily mistaken the one for the other.

Proximate Principles Common to Animals and Plants.

	Albumen		Casein		Fibrin	
	Animal	Vegetable	Animal	Vegetable	Animal	Vegetable
Carbon .	53·5	53·5	53·5	53·7	52·8	53·2
Hydrogen .	7·0	7·1	7·1	7·1	7·0	7·0
Oxygen .	23·7	23·3	23·6	23·5	23·7	23·4
Nitrogen .	16·5	16·5	15·8	15·7	15·8	16·0

Extend the comparison to the organic system in which the first manifestations of life—the egg and the grain—are produced; both the elementary and the proximate com-

position are the same. The following table will throw more light on the subject than a long enumeration would do:—

Comparative Composition of the Egg and the Seed.

EGG.	SEED.
Albumen	Albumen
Fatty matter	Fatty matter
{ Sugar of milk	Starch, afterwards developing—
{ Glucose	Sugar
Sulphur and phosphorus entering into organic compounds	Sulphur and phosphorus entering into organic compounds
Divers salts—phosphates	Divers salts—phosphates
Water, 65 to 90 per cent.	Water, 10 to 12 per cent.

In both cases the composition is very similar; except that there is more moisture in the egg than in the seed, everything is alike. But what is perhaps more unexpected is that the condition which gives the first impulse to the vegetable germ is the same which causes the animal germ to spring into life. What is necessary to both? Moisture and warmth. The egg possessed moisture naturally; give it to the seed by placing it on a wet sponge, raise the temperature, and in both cases the life hitherto latent will manifest its activity.

The seed absorbs the water; its tissues swell and ramify; the starch contained in the cotyledons is dissolved, and passes into the state of dextrin and glucose; one part of the nitrogenous matter, fibrin and legumen, dissolves and passes into the state of albumen, the seed then absorbs oxygen and evolves carbonic acid; it breathes, as it were, and the embryo, assimilating the modified principles of the seed, gives forth what botanists call the two axial systems—the stalk furnished with leaves and the roots provided with their capillary filaments, which are the special channels of absorption of the plant.

Thus by a transformation of the actual substance of the seed the plant is formed, which possesses in variable degrees organic irritability, but which, deprived of the power of motion, remains fixed in the soil where the seed germinated.

In the egg—a hen's egg, for example—an elevation of temperature is also necessary to determine the evolution of the germ, and to cause it to go through all the phases of embryonic life; but to be successful, this evolution requires the aid of oxygen. The egg respires like the grain, and like it evolves carbonic acid. Its contents experience an extraordinary chemical and organic transformation. One part of the yolk is changed into glucose, and at the same time becomes

the seat of a work of segmentation, the prelude to the formation of organs by the union of which the chicken is formed; this will, at a fixed date, break from the shell as the plant comes forth from the grain, endowed like it, but in a higher degree, with organic irritability, and further gifted with the faculty of locomotion.

From whence comes the plant? Entirely from the substance of the seed. And the chicken? Entirely from the substance of the egg—the transformation in both cases being due to the elevation of temperature and the presence of oxygen. From this we draw two legitimate and very important conclusions.

1. Plants and animals spring substantially from a common base.

2. They are born by means of similar actions determined by a common cause, namely, heat.¹

But from the moment when the leaves, issuing from the envelope of the seed, receive the action of the sun's rays, and from the moment when the chicken, proceeding from the egg, begins to subsist upon aliments drawn from other sources, although their activity may be referred to a series of common effects, yet others are produced, the contrasts and opposition of which in plants and animals, if we regard only the final result, form two essentially different systems.

We will apply ourselves to defining the contrasts, and when we have fixed by this study the condition of life both in the plant and in the animal we will descend from the heights of theory into the domain of practice, for we must not lose sight of the end we have to attain, which is to obtain the largest possible profit from cattle.

When the leaves first issue from the seed they are white or pale, but as soon as they are submitted to the influence of light a sudden transformation takes place in their organisation: from a yellowish white they become a deep green, and on observing their tissues by the aid of a microscope we find them gorged with green granules. Now, these granules spread in profusion over the parenchyma of the leaves. Each granule is really a vegetable atom, possessing in an almost infinitesimal state of unity all that the plant itself possesses of strength and of activity. Each one of these granules is in fact the seat of such remarkable actions as the following: When the sun appears above the horizon, and its rays first light upon the surface of the leaves, we see the granules

¹ It must be understood that in saying they are born I mean that their vital activity is brought into play.

of chlorophyll grow larger and multiply, and other white granules form in and around them which are composed simply of starch; and when, in rare cases, there is a deficiency of starch granules, then the tissue of the leaf is gorged with sugar and glucose. But where does this glucose or starch, which is formed of carbon, hydrogen and oxygen, come from? From the carbonic acid of the air and from rain-water, of which the earth is the natural reservoir. It is the carbonic acid that the granules of chlorophyll first absorb, and afterwards decompose to separate from it the whole of the oxygen.

This extraordinary act of reduction is itself followed by the combination of the carbon with the elements of water. Strictly speaking, these two acts are simultaneous. It is then proved that leaves, the tissues of which often possess the delicacy of the finest lace, exceed in power all the means of reduction that our laboratories afford. But in order to manifest their activity the granules of chlorophyll require that the rays of the sun should vivify and animate them.

In fact, when the sun disappears below the horizon it produces a sudden change in the functions of the leaves. The absorption of carbonic acid ceases, the absorption of oxygen—limited up to that time to very slight proportions, first to preserve the irritability of the tissues—becomes the dominant feature of their activity. After this absorption a transformation takes place in the composition of the leaves. The granules of chlorophyll remain, but the starch granules disappear—they are dissolved. Once dissolved they enter into the general circulation of the plant, and there encountering nitrogen, by a still inexplicable act of synthesis, determined by the return of light, they are partly transformed into protein matters.

While this transformation is taking place the plant is putting forth new leaves, which find in the dissolved starch, glucose and protein—substances whose origin we have just explained—the first elements of their tissues, as the embryo had itself found them in the grain; and thus with old and new formations the vegetable gains each day in substance, the organs which came last are the compound product of part of the substance of those which have preceded them, increased by agents drawn from without. This succession of remarkable effects is carried on without interruption, but with variable intensity, up to the time of flowering. At that time a new order of things begins. Plant life enters into a different course, which brings it back by gradations to the acts of animal life. As soon as the flower is in bloom and

the young seeds begin to develop, the growth of the plant gradually lessens and soon stops completely, and the flower, instead of absorbing carbonic acid into its substance and drawing in light and heat like the leaves, absorbs oxygen, sets free carbonic acid, and radiates heat. There are some flowers, such as certain kinds of arums, the temperature of which rises from 18° to 64° and even 72° F. above the surrounding temperature.

An important part of the substance of the plant is conveyed to the seed, the formation of which it secures. Then the plant absorbs nothing more from outside; it lives on itself in order to ensure the organisation of the embryo and the grain which is to reproduce it, and which remains the synthetical expression of all the former efforts.

There are, then, in plant life three totally distinct phases.

At the beginning and the end the plant absorbs oxygen, and in the intermediate period carbonic acid. The contrast between these three periods is very marked. At the commencement, when it sprouts, the plant produces heat; at the end of its evolution, when flowering, it still produces heat. In the intermediate period, on the contrary, it absorbs heat, and this heat which it receives from the sun it changes by means of that chemical affinity that remains in a latent state in all its productions. Now, as this period excels the two others by its intensity and the paramount importance of the products which were born of it, it may be said with certainty that plants are great consumers of heat. We may add as a last trait of plant life that plants proceed from relatively simple compounds, carbonic acid, water, nitrates, ammoniacal salts, nitrogen and mineral salts, all substances having their affinities complete, and which, by an absorption of heat, it transforms into more complex compounds, the affinities of which are in a high state of tension, such as starch, sugar, cellulose and albuminoid matters, whose texture, composition and properties are modified by the slightest actions. I repeat, at the risk of being wearisome, that the prime mover of vegetable activity is the sun, and the culminating characteristic of vegetation is the facility it possesses of drawing its productive power from the light and warmth of the sun.

But when we pass to animal life we shall find the conditions of its activity to be quite the opposite. Take the chicken just emerged from the shell. As long as it lives it will absorb oxygen; it will consume the products of unstable affinities in order to form others with constant affinities; it will give off heat, which heat it will obtain

from the combustion of a part of its food, or from its own substance, which arises from it. I repeat that as long as it lives it will absorb oxygen, and the final result of its activity will resolve itself into a series of acts of combustion.

If, parallel with these effects, others are produced which manifest themselves by the formation of special compounds, such as sugar, fats, albuminoids, muscular and nervous tissues, accomplished by methods of synthesis analogous to those which are set to work by plants, we must not lose sight of the fact that these effects have for their determinative and regulating cause the permanent and parallel acts of combustion, which are the source of the heat that animates the animal machine, without which its functions would cease.

Acts of combustion are always the first condition of physiological formation.

The animal needs air and water, but does not live on them. If he is provided with nothing else he becomes emaciated, enfeebled and dies. His activity depends upon his food, one part of which is assimilated, and the other directly or indirectly destroyed. Life in the two kingdoms, vegetable and animal, exhibits a multitude of common traits and similar effects; but if we consider only the final result, the preponderative and characteristic work, we find that plants derive their activity from the sun by processes of reduction, whilst animals exist by the combustion of their food, or of the tissues which are formed from it, to become exhausted by the renovating act of vital labour.

A man who ascends Mount Blanc consumes nearly 4,632 grains of carbon, whilst the most perfect steam-engine to do the same amount of work would consume 18,528 grains. The animal machine excels therefore in economy and perfection, but the useful effect obtained is due to the same cause.

On the contrary, a plant which fixes in its tissues 4,632 grains of carbon gives back 2,880 heat units, equal to half a day's horse-power.

On this point the opposition is radical. But where the contrast between the two systems is most clearly defined is that the plant, which receives through the medium of the sun 10 fertilising units, gives back by the crop at least 100 units; whilst the animal, which receives 100 alimentary agents, returns at most only 10 organised products. And the reason is this. The sun is the motive power of vegetable activity, and air and water the sources whence it

draws nine-tenths of its substance; whilst the animal has to obtain by food both the warmth that animates it and the substance that nourishes it. Now, everybody knows that to evolve the heat that is contained in the component parts in a state of chemical affinity it is absolutely necessary to burn them and to destroy them.

We will make a short *résumé* of the foregoing facts.

Comparing the substance of animals and plants we find that there is a complete identity between the two. If the comparison be extended to the active principles, the identity is still maintained.

With respect to the acts into which their life is divided, the similarity frequently exists without being absolutely constant. But if we stretch the parallel to the forces which animate the two kingdoms the opposition is radical. Plants absorb light and heat, which they change into chemical affinity. Animals, on the contrary, restore the chemical affinity to the state of heat. The opposition is maintained if we compare their origin.

If we accept the theoretical ideas I have just presented to you in order simply to arrive at useful and practical results, a new trait common to the two kingdoms becomes apparent. We find in agriculture that the rôle of plants and of animals is reduced definitely to that of simple machines. If we wish to produce bread we sow wheat; if sugar we have recourse to the cane; and if oil, to colza or poppies. How do they manage in the colony of Australia, whence tallow and wool are exported to Europe? They cultivate grass land, and the grass land maintains sheep. Two successive acts of transformation are accomplished, which acts we are able to regulate and control, and the effects of which, though amenable to various and striking contrasts, have yet their origin in the same laws.

All the art of cattle-feeding rests in fact upon the principle of *collective forces* and the notion of the *dominants*; and the economical production of cattle upon the principle of *high feeding*. Henceforth I shall not speak of the laws of vegetation, I shall call them the laws of life, and shall use every effort to give you practical proof of this demonstration. I shall thus hope to justify the resolution that, after a good deal of hesitation, I have taken to speak to you of live stock, and the means to be employed to deprive them of the appellation of necessary evils which has hitherto attended their production, and which will as certainly be abandoned as the empirical methods of live-stock rearing which gave rise to it.

You know that in order to obtain large crops it is necessary to give to the earth by means of manure the four following substances :—

Phosphates	|	Lime
Potash		Nitrogenous matter

In order to live, grow, develop, and give meat, milk, wool, or strength, animals must also receive through their food four substances :—

Albuminoid matter	|	Carbohydrates
Fatty matters		Salts or mineral matter

Regarded from a practical point of view the analogy is remarkable. The products are different, the number is the same.

You know, further, that the four substances of which manure must be composed have their full effect only when all four are in combination; the association is so essential that the suppression of one only suffices to reduce in a considerable degree, if not to annul altogether, the effect of the three others. In order to leave nothing vaguely understood, I will recall the example already cited of the cultivation of colza, where every condition being the same—such as aspect, soil and culture—the suppression of nitrogenous matter was sufficient to cause the crops to fall from 43 bushels to 16½.

With regard to animals it is precisely the same. The suppression of one of the four constituents necessary to animal life—albuminoid matter, fatty matter, carbohydrates, or mineral matter—produces such a check upon the work of nutrition, that after a succession of more or less serious indispositions, the death of the animal is almost always the result. A dog placed upon an exclusive diet of meat—carefully washed in order to bring it back as much as possible to the state of fibrin—soon shows an almost invincible repugnance to the food, and these symptoms are followed by intestinal irritation, to which he eventually succumbs.

Carbohydrates alone do not succeed much better. Majendie has left us his experience on this subject. An ass fed only on rice will not live more than three weeks. A diet of fatty matter alone is more defective still. A duck fed entirely upon butter dies from inanition in less than three weeks. Butter exudes from all parts of its body, and it emits a disgusting odour something like that of butyric acid. The excretions themselves are almost entirely formed of fat.

The suppression of mineral matter is the last item, and of the minerals, the suppression of common salt (sodic

chloride) only will give rise to diseases from which death is certain in time to ensue.

Regular nutrition, which manifests itself only in perfect health and in an increase of weight, is to be realised only by means of the association of the four above-mentioned constituents.

The effect of each one of these four classes of substances is increased, not only by association with the three others, but by the proportion by weight in which they are combined. In fact, if you vary the proportion of each of the four constituents one after the other, you will find that the albuminoid and fatty matters have more influence over the production of cattle than the carbohydrates. We will demonstrate these two fundamental propositions by a simple example; and milk, which may be taken as the type of animal food, will furnish us with the means of doing so. Its composition justifies the necessity for the four terms.¹

Milk contains in fact—

Casein	Albuminoid matter
Butter	Fatty matter
Sugar of milk	Carbohydrates
Salts	Mineral matter

¹ *Mean Composition of Cow's Milk.*

Water	87 per cent.
Solids	13 per cent.

	In 100 parts	
	Milk	Dried milk
Casein	3·60	28·00
Butter	4·03	31·00
Sugar of milk	5·50	42·00
Salts	0·40	3·00

Composition of the Salts.

	In 100 parts of milk
Calcic phosphate	0·231
Magnesian phosphate	0·042
Ferric phosphate	0·007
Potassic chloride	0·144
Sodic chloride	0·024
Sodic carbonate	0·042

I now pass to my second proposition, namely, the preponderant action of the albuminoid and fatty matters. Three parallel experiments will suffice to establish this fact.

Give to one calf some skimmed milk, to another the same quantity of skimmed milk with the addition of a little whey, and to a third the same quantity of milk not deprived of its cream, and see how different the results are. In the course of a week the first calf will have increased 13 lbs., the second 26½ lbs., the third 48½ lbs. What has the second calf received more than the first? sugar of milk and carbohydrates. And the third? an excess of fatty matter and albuminoid matter. The exact details of this important experiment are as follows:—

For every 100 lbs. of living weight the three calves received—

	Casein	Fatty matter	Sugar of milk	Increase obtained
	lbs.	lbs.	lbs.	lbs.
1. Skimmed milk	4·6	1·2	5·5	13
2. Skimmed milk and whey	4·6	2·0	7·7	26½
3. Pure milk and cream	5·1	7·5	6·3	48½

Note the progression—

	Increased weight lbs.
1. With insufficient rations	13
2. „ more carbohydrates	26½
3. „ more protein and fatty matter	48½

Compare these results with those obtained with colza, with mineral manure, and the normal manure.

	Field of grain Per acre Bushels
Soil without manure	7½
Mineral manure without nitrogen	16½
„ with 88 lbs. of nitrogen added	27½
„ with 176 „ „	46

Here the mineral manure corresponds to the ration to which carbohydrates were added, and the normal manure with 88 or 176 lbs. of nitrogen added to the ration with an excess of protein and fatty matter. In the face of these proofs it is impossible to deny the preponderant action of protein and fatty matter, or in the manure the preponderant action of nitrogenous matter.

The notion of dominants and the principle of collective forces is then applicable as much to animals as to plants, and the conditions of production in the two kingdoms are subject to the same laws.

The great superiority of fatty matters over carbohydrates is explained by their heat-producing power. Taking equal weights of each, the combustion of the fatty matters will produce $2\frac{1}{2}$ times more heat than carbohydrates. The quantity of fatty matter that can be consumed by those living in high latitudes almost passes belief. The Laplanders drink train oil as we ourselves drink wine and beer. The rigour of the climate, against which they must be protected by activity of respiration, explains both the need and the faculty of assimilating such quantities of fatty matter. By their aid animals utilise with less effort that part of their food that is to be assimilated and converted into animal products. Never lose sight of the important fact that we must think of food as consisting of two parts—one which animates the machine, and the other which is transformed by it.

Fatty matters occupy the first rank as heat-producing aliments, then come carbohydrates, and lastly albuminoid matters; the latter, however, take the pre-eminence as physiological elements for the formation of tissue and of animal products generally. Do these distinctions, authenticated by recent experiments, justify the opinion which was at one time held that animals are incapable of producing anything by themselves, and that their function is simply to accumulate and isolate in their tissues the various substances contained in their food?

Nothing can be more opposed to the actual phenomena than such an opinion. The truth is, that animals create their substances as plants create theirs. Before taking part in the function of the animal, aliments undergo complete modification, which entirely changes their nature. To quote only one example, borrowed from M. Chevreul: cooked meat becomes, as it were, uncooked, and in part passes again, in the animal organism, into the state of flesh, fat and living tissues.

The idea that albuminoid matters have no part in the production of animal heat has no better foundation; for the increasing formation of urea, which is derived from them by means of oxidation, is a proof to the contrary.

But it is also true that in this part of physiological work fatty matters and carbohydrates play a more important part than albuminoid matters, whilst they contribute, though in a more restricted degree, to the work of nutrition. In a word,

sooner or later all nourish and all oxidise, but in a different proportion. In the two kingdoms the work of nutrition is carried on by a system of analogous actions, which are oftentimes identical.

But beyond these analogies there is a difference which dominates all, and finally assigns to the animal and vegetable kingdoms a different function in the economy of animated nature. Let us recall it once more.

Plants spring from mineral compounds whose affinities are complete. They absorb the light and heat of the sun into their substance, where it passes into a state of chemical affinity incompletely neutralised. Animals, on the contrary, proceed from organic compounds in which the incomplete affinities are in a high state of tension, whence they draw at the same time the warmth that animates and the substance that nourishes them. This is the great difference between the two kingdoms.

But to return to the practical facts of cattle-feeding, I will strengthen, by another example, the rules that I have just indicated to you, and to these notions add the proof that if high farming only is remunerative, abundant alimentation judiciously proportioned will alone cause cattle to realise a profit.

The elements of the new demonstration I shall borrow from the already well-known experiment of M. Boussingault. Submit a young pig, 132 lbs. in weight, to a diet composed exclusively of potatoes. After 93 days of this treatment the pig will have gained $15\frac{1}{2}$ lbs. of flesh. He weighed 132 lbs. at the commencement of this experiment; at the end of it he weighed $147\frac{1}{2}$ lbs., and to produce this he was made to consume 1,173 lbs. of potatoes. This assuredly is a poor result. Make another experiment: upon a second pig, weighing 143 lbs. Only instead of potatoes and nothing else, give him plenty of rye meal, crushed peas and hog wash, into which all the leavings of the table and dairy are put.

Potatoes which are rich in carbohydrates contain very little fatty matter, and still less of protein compounds.

By an addition of peas, rye meal and hog wash, we pass from an incomplete and insufficient diet to a complete, nourishing and properly proportioned ration, and approach, without, however, attaining, the conditions under which the animal is placed during the period of lactation.

With the second ration the increase is more rapid and considerable. In 93 days it rises 101 lbs., instead of $15\frac{1}{2}$ lbs.¹

¹ The increase stated refers to dead weight.

How much food had the pig consumed under an exclusive diet of potatoes? 1,172½lbs., which corresponds to 286 lbs. of dry matter.

In the second experiment the amount of food consumed was 3,665 lbs., representing 563 lbs. of dry matter, or twice as much as in the first ration, but on the other hand, by doubling the ration, we have multiplied the product six times.

	Amount consumed	Increase obtained
By an exclusive diet of potatoes . . .	lbs. 286	lbs. 15½
By a complete and nourishing diet . . .	563	101

Pig's Rations.

FED WITH POTATOES ONLY.

Undried potatoes	Dry potatoes	Protein compound	Fats	Carbohydrates	Salts
lbs. 12·76	lbs. 3·07	lbs. 0·32	lbs. 0·025	lbs. 2·57	lbs. 0·101

In 93 days to eat :—

Undried potatoes	Dry potatoes	Protein compounds	Fats	Carbohydrates	Salts
lbs. 1186·68	lbs. 285·51	lbs. 29·76	lbs. 23·25	lbs. 239·01	lbs. 9·393

During this period of 93 days the pig gained 15·4 lbs.

At the end of the experiment it weighed . . .	lbs. 147·4
At the beginning	132·0
	15·4

Pig's Rations.

HIGH FEEDING.

Food	Total weight	Dry matter	Protein compounds	Fats	Carbo-hydrates	Salts
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Potatoes .	10·71	2·58	0·25	0·02	2·16	0·10
Crushed rye .	0·99	0·85	0·12	0·02	0·64	0·02
Rye meal .	0·70	0·55	0·11	0·02	0·48	0·02
Raw peas .	0·78	0·67	0·18	0·02	0·42	0·02
Hog wash .	22·00	1·03	0·19	0·09	0·62	0·14
	35·18	5·68	0·85	0·17	4·32	0·30
In 93 days	3,271·74	528·240	79·05	15·81	401·76	27·90

During this period the pig gained 103·4 lbs.

At the end of the experiment he weighed . . .	lbs. 246·4
At the beginning	143·0

103·4

If the animals are poorly fed, it is necessary to have 7 pigs in order to produce 1 cwt. of pork in 93 days. But let the animals be plentifully fed, and the same result, that is to say, 1 cwt. of pork, may be obtained with only a single pig! Now, which of these two methods is the better, the more economical and the more advantageous? Is it better to keep 14 pigs or 2 only? With the 14 pigs it is necessary to have large pig-sties and numerous labourers. The general expenses of labour, building and interest of capital are the same whether the animals are well or badly fed; and the cost per pound of meat is less in proportion as the increase is greater. Always then remember the theory of high farming. Feed your cattle well, and go in for remunerative culture.

Cattle have been called a necessary evil. How can they be otherwise if they are badly fed? What can be expected from an animal fed on straw or forage? Yet what is the system to which cattle in three-fourths of our southern departments in the Landes and in the mountains of Puy-du-Dôme and of Vivarais are submitted? I repeat that when the diet is uncertain and badly proportioned, though of equal weight, its useful effect is less than when it is superabundant in the desired quantities, and contains the four

constituents I have already mentioned. When we feed a pig upon potatoes only 1 cwt. of food produces an increase of $6\frac{1}{2}$ lbs., when it is fed upon a full and complete diet 1 cwt. of food gives an increase of 20 lbs.

The same fact is shown in a more decided form by 3 calves under a respective diet of skim milk, milk with whey added, and milk with cream added, because in the latter case the diet is richer, and during the period of lactation the increase is more rapid.

1 cwt. of skim milk produced	58½ lbs. of meat
„ milk with whey added produced	99 „
„ „ cream „	127 „

M. Kühn reports that 6 oxen, weighing on an average about 11 cwts. each, placed under a diet rich in fatty matter, increased 12 cwts. $3\frac{1}{2}$ qrs., and that 6 others placed upon a less rich diet gained in the same time an increase of 8 cwts. $1\frac{1}{2}$ qrs.¹

We always come to the same conclusion : the most rapid and stimulating fattening is the most economical and remunerative.

These analyses are singularly instructive, they throw great light upon the rules which must be applied to cattle-feeding; abundant nourishment must be given, and the rations must contain suitable proportions of the four constituents before mentioned. If a diet contains an excess of carbohydrates in the form of starch, and lacks in consequence fatty matter and nitrogenous matter, a part of the starch and cellulose will be found in the excreta without having undergone the slightest alteration. But the starch in the manure is of no use. It contains only carbon, oxygen and hydrogen; that is to say, the elements that the plant is able to obtain from the air and from water. If, on the contrary, the dose of nitrogenous matter is too strong and that of the fatty matter too feeble, a part of the nitrogenous matter passes in its turn into the excreta. But this time all is not lost, for we know that the nitrogenous matter of animal or vegetable origin forms a most powerful manure, only the nitrogenous matter is not of so much value as a manure as it is as an aliment; there is therefore some loss. Again, if the quantity of fatty matter is too great it provokes more serious mischief with the digestive organs, and you will find both nitrogenous matter and carbohydrates in the excreta.

¹ Kühn's treatise on *The Alimentation of the Bovine Race*, p. 290.

It was long believed that cellulose¹ was devoid of all alimentary properties, but numerous experiments made with the greatest care have proved this opinion to be ill founded, and that in reality 50 per cent. of the cellulose contained in fodder enters into the work of nutrition, doubtless with less efficacy, but as certainly as starch and saccharine matters.

The intervention of saline matter is not less essential. It has been ascertained that in the absence of potash, a dog which is otherwise well fed exhibits in less than a month all the phenomena of inanition.

I have already said that the suppression of salt produces serious indisposition; practically we need only concern ourselves with phosphates and salt, for through water and food the animals receive more of the other minerals than they can utilise. The conclusion of all this is that we have a correct equilibrium to establish: an equilibrium that depends on two points, the amount of food proportioned to the weight of the living animal and the composition of the ration itself. We must, however, defer the further consideration of their importance to the next lecture. In the present one, theory, not practice, has had the precedence, but in the next lecture this order of things will be reversed and the preference will be given to practice, for we shall not only fix the amount of food necessary for animals, but endeavour to throw light upon the financial side of the question of cattle raising, and determine the profit that may be derived from it, whether it occupies the foremost place or only a secondary one in the economy of the farm.

¹The following, according to M. Kühn, are the amounts of cellulose which are dissolved and digested in the case of the principal fodders:—

	Per cent.
Oat straw	55
Wheat straw	55
Bean straw	36
Clover hay	39
Meadow hay	60

LECTURE XIV.

CATTLE—THEIR FOOD—THEIR IMPORTANCE IN FARMING—THE PROFIT WHICH THEY GIVE.

I HAVE already told you that in the feeding of animals it is necessary to take into consideration the weight of the animal, the composition of the food which is to form its support, and the amount of food that may be given without disturbing the digestive functions, which vary in power in different animals. These weights may be fixed thus:—

Weight of Dry Food for every Cwt.

	lbs.
Cows	2 to $2\frac{1}{3}$
Oxen for draught	2 „ $2\frac{1}{3}$
„ fattening	3
Sheep	2 „ $2\frac{1}{2}$
Pigs	3 „ 4

The average weight of a cow or an ox being about 10 cwts., say 1,100 lbs., if we take this weight as a unit by which the various animals may be measured, we obtain the following as an expression of the weight of rations necessary for 24 hours:—

Dry Rations for 1,100 lbs. of Live Weight.

	lbs.
Cows	$26\frac{1}{2}$
Oxen for draught	$26\frac{1}{2}$
„ fattening	33
Sheep	$26\frac{1}{2}$
Pigs	$39\frac{1}{2}$ to 44

I now pass to the second question. In these different rations what proportion of the four constituents, protein, fatty matter, albuminoid matter and salts, should be used? The following particulars are borrowed from M. Emile Wolf, and they have been confirmed both by science and practice:—

For 1,000 lbs. of Live Weight per day of 24 hours.

	Protein	Fatty matter	Carbo- hydrates
	lbs.	lbs.	lbs.
Milch cow	3·520	0·770	17·60
Draught ox	3·960	1·100	15·84
Ox for fattening	4·620	1·650	14·08
Sheep not being fattened	3·300	0·660	16·50
Sheep fattening	5·960	1·100	14·96
Pig	7·150	1·100	35·20
Pig fattening (last period)	9·900	2·200	29·70

I say nothing of saline matters, because with the exception of salt, which everybody knows how to use, the animals would under such a system be abundantly provided with them.

In these different rations the fatty matters are almost a third of the albuminoids, and in their turn the albuminoid matters oscillate between a third and a fifth of the fatty matters and the carbohydrates.

It is usual to express these two relations as follows:—

Relation of fatty matter to protein	1 : 3
Nutritive relation of the food	1 : 5

Whilst remembering the utility of these summary expressions, it is well, in order to have an exact idea of the system, to go back to the respective quantities of the three constituents of the ration, inasmuch as when we increase the proportion of fatty matter by an addition of oil-cake, or that of protein by the addition of meal or peas, the carbohydrates which these foods contain appear to be too small in the diet, and seem to lessen the improvement that the ration has received from the substances added.

In milk, which corresponds to the most active period of animal life, we find that the fatty matter figures in the same quantity as the protein, and that the latter is almost the half of the sum total of fatty matter and carbohydrates.

In 100 parts of Milk.

	Per cent.
Casein	3·60
Butter fats	4·03
Sugar of milk	5·50

Theory.

RELATIVE NUTRIMENT.

	Per cent.
Protein	1·00
Fatty matter	1·00
Carbohydrates	2·60

Practical cattle feeders are unanimous in the opinion that for ordinary feeding purposes it suffices to give as much fatty matter as is equal to one-third of the protein 1 : 3, and of protein in its turn one-fifth of the sum total of fatty matter and carbohydrates 1 : 5; but for fattening purposes it is necessary to increase the amount of fatty matters from one-third to two-thirds, and of protein from one-fifth of the sum total of fatty matter and carbohydrates to one-third. We then come nearer to the composition of milk without attaining its richness. As an application of the preceding rules, I give below examples of rations for milking cows and oxen that are in process of fattening. With respect to milking cows I quote from M. Kühn the progression it is best to follow in order to obtain the maximum amount of milk:—

Quantity of Food used in a Stable of Twenty Cows.

Per day per head	Dry matter	Protein compounds	Fatty matter	Extractive matter non-nitrogenous
	lbs.	lbs.	lbs.	lbs.
4·4 lbs. of dry clover .	3·663	0·616	0·154	1·672
3·3 „ meadow hay .	2·827	0·275	0·099	1·265
1·1 „ common hay .	0·946	0·088	0·017	1·264
7·7 „ barley straw .	6·600	0·495	0·154	2·519
5·5 „ wheat straw .	4·719	0·110	0·081	1·573
2·2 „ chaff .	1·881	0·099	0·033	0·704
55·0 „ beetroot .	8·030	0·825	0·195	4·972
	28·666	2·508	0·733	13·969

Progression of Rations.

Per day per head	Dry matter	Protein compounds	Fatty matter	Extractive matter non-nitrogenous
Normal ration	lbs. 28·66	lbs. 2·51	lbs. 0·73	lbs. 13·71
3·85 lbs. of ground rye . .	3·30	0·42	0·07	2·58
	31·96	2·93	·80	16·29
Normal ration	28·66	2·51	0·73	13·71
4·4 lbs. of bran	4·00	·63	·14	2·31
	32·66	3·14	·87	16·02
Normal ration	28·66	2·51	0·73	13·71
2·2 lbs. of oil-cake . . .	1·83	0·62	·21	0·54
	30·49	3·13	·94	14·25
Normal ration	28·66	2·51	0·73	13·71
2·64 lbs. oil-cake	2·24	0·74	·27	·64
	30·90	3·25	1·00	14·35

In these rations the quantity of protein is a little less than in Wolf's formula, but the amount of fatty matter is increased by way of compensation. The same author gives the three following formulæ as applicable to oxen that are being fattened; they relate to three periods of the operation—the beginning, middle and end.

If these rules have neither the simplicity, strictness nor certainty of those that I have given you with respect to plants, if the facts upon which they are based are less numerous, they nevertheless constitute extremely valuable indications. A fat ox, according to the old calculation, gained at least 2 lbs. live weight per day, therefore the same ox put upon rational diet will gain 4 lbs. each day, or just double. But in order that the practical result may agree with the theoretical statements, it is necessary to avoid in the formula of rations the substitution of substances that are too dissimilar, or adding any but analogous

ones, that is to say, those which possess about the same degree of digestibility, volume and richness.¹

It is plain that, supposing the quantities to be equal, the protein that exists in wheat, peas or maize is more

First Period.

BEGINNING OF FATTENING.

Ration per day per head, 1,100 lbs.	Dry matter	Protein compounds	Fatty matter	Extractive matter non-nitrogenous
55 lbs. of beetroot	lbs. 6·60	lbs. 0·61	lbs. 0·06	lbs. 4·95
4·4 „ chopped oat straw } 5·5 „ ditto given before } last feed	8·48	0·25	0·20	3·52
8·8 „ dry red clover . . .	7·40	1·17	0·28	2·50
3·3 „ oat bran	2·88	0·45	0·10	1·66
4·4 „ oil-cake	3·74	1·24	0·42	1·07
0·5 „ linseed meal	0·48	·12	0·20	0·10
0·11 „ salt	0·11	...	...	...
	29·69	3·84	1·26	13·80

Second Period.

FATTENING IN FULL PROGRESS.

Ration per day per head, 1,100 lbs.	Dry matter	Protein compounds	Fatty matter	Extractive matter non-nitrogenous
66 lbs. of beetroot	lbs. 7·92	lbs. 0·74	lbs. 0·06	lbs. 5·94
4·4 „ chopped oat straw } 4·4 „ ditto given before } last feed	7·54	0·22	0·17	3·13
8·8 „ dry red clover . . .	7·40	1·17	0·28	2·50
3·3 „ best chaff	2·88	0·45	0·10	1·66
6·6 „ oil-cake	5·61	1·86	0·63	1·60
1·0 „ linseed meal	0·96	0·24	0·40	0·19
0·15 „ salt	0·15	...	...	...
	32·461	4·68	1·64	15·02

¹It must be remembered that the whole of the nitrogen in feeding stuffs is not present as albuminoids. Hence a mere ultimate analysis throws no sufficient light on their nutritive value.

Third Period.

END OF THE FATTENING PROGRESS.

Ration per day per head, 1,100 lbs.	Dry matter	Protein compounds	Fatty matter	Extractive matter non-nitrogenous
	lbs.	lbs.	lbs.	lbs.
55 lbs. of beetroot	6.60	0.61	0.06	4.95
3.3 „ chopped oat straw	5.66	0.16	0.14	2.34
3.3 „ ditto given before last feed				
8.8 „ dry red clover	7.40	1.17	0.28	2.50
4.4 „ ground barley	3.77	0.44	0.10	2.82
5.5 „ oil-cake	4.67	1.55	0.52	1.33
1.6 „ linseed meal	1.45	0.36	0.61	0.29
0.2 „ salt	0.20	...	...	...
	29.75	4.29	1.71	14.23

valuable than the protein found in furze or buck-wheat, haulm, and the fatty matter in oil-cake is more valuable than the green substances which we extract from leaves by means of ether.

If we wish to employ substitutes which we have arrived at by theory, in the form of substances having no likeness to each other, and draw up a table of nutritive equivalents resting on a similar basis, we shall be only seeking failure which a comparison of known foods of similar composition would lead us to avoid. Another recommendation upon which I cannot insist too positively is to advance gently when we wish to change the ordinary food of an animal for fattening food, especially when the dry fodder of winter is changed for the green crops of spring.

But this does not form a limit to our means of action with respect to animals. All the domestic species do not possess the same assimilative power. For an equal consumption of food they give neither the same product nor the same work.

With 1 ton 2 cwts. of fodder, according to Lawes, oxen give 220, sheep 264 and pigs 572 lbs. of live weight. This difference may be represented in another way, namely, by time. The following is the equivalent for one month:—

	Per cent.
Pigs increase	6
Sheep „	1.75
Oxen „	1.00

In the same way we are able to obtain analogous effects by selecting particular breeds and the creation of a more perfect stock. A Durham ox attains full growth in four years, whilst it takes at least six to gain the same result with French cattle.

By the crossing of merinos and Dishley sheep we are able at the same time to obtain finer wool and greater development of flesh. The same observations apply to milch cows, amongst which we can foresee and even prolong the duration of the secretion of milk.

But what is more remarkable in the more perfect races, besides the greater precocity which enables us to clear our capital more quickly and to multiply operations, is the really extraordinary development acquired by the fleshy parts, the prime joints, as the butchers call them, to the prejudice of the poorer parts and offal. In the Durham breed, for example, the head and bones are reduced to the smallest dimensions, the legs are short, the paunch narrow, the skins fine and supple, whilst the beast is bulky, the space between the haunches largely developed, and the muscular masses so considerable that by themselves alone they form two-thirds of the total weight of the animal.

The same may be said with reference to the Dishley sheep; besides a greater fineness of the wool the fat concentrates in a series of layers about the fleshy parts, giving a highly appreciated flavour to the meat. Again, is it not a fact worthy of remark that the flesh of well-fed animals, in good condition when killed, contains, comparing the prime parts, one-fourth more nutritive power than weakly lean animals that have been niggardly reared?

What an argument in favour of abundant and rational feeding.

Composition of Fat Meat compared with Lean Meat.

	Muscular substance	Fat	Ash	Water
Fat beef contains	356	239	15	390
Lean	308	81	14	597
Difference in favour of fat beef .	+48	+158	+1	-207

Certainly no one admires more than I do works of art, but is not that also to be called a great art which sculptures

life, which has to deal not in the dead inert matter, with neither reaction nor resistance, but with animated marble

	Lean beef			Fat beef		
	Neck	Saddle	Three first ribs	Neck	Saddle	Three first ribs
Water	77.5	77.4	76.5	73.5	63.4	50.5
Fat	0.9	1.1	1.3	5.8	16.7	34.0
Ash	1.2	1.2	1.2	1.2	1.1	1.0
Muscular substance	20.4	20.3	21.0	19.5	18.8	14.5
Dry substances .	22.5	22.6	23.5	26.5	36.6	49.5

that must be shaped in life and modelled even down to the blood, nerves, motion and will? In Bakewell's day it was believed the choice of breeds was of more importance than the system under which animals were fed, but it has since been discovered that this is an error, and that of the two means, high feeding is in the end more effective, and attended with better results. As Descartes well said, "Nutrition is continuous". The first improvements in the organisation of species are the fruit of regular and judicious feeding. The influence of breeding being added to that of proper feeding system, we are in reality only one degree nearer perfection, because the qualities transmitted by the reproducers to their descendants add by inheritance the influence of what was good in the old system of feeding to the good effects of the present system. Most people know that with bees the sex depends greatly upon the food that they receive, and that the queens or fruitful ones owe the attributes of their sex chiefly to superabundance of nourishment. In the same order of ideas we may mention the tadpoles that William Edwards prevented from passing into the state of frogs, by depriving them of light, and compelling them to breathe in water.

What hosts of interesting facts the study of the training which forms part of our *régime* would reveal, if from the horse we extended it to man himself in the various conditions occasioned by differences of climate, manners, fortune and profession. To quote only a few examples. In children "rickets" are due to deficient nutrition, or to food which is either too rich or too poor in nitrogenous matter, to the exclusion of carbohydrates.

Nor can we pass over in silence the extraordinary results, though in an opposite sense, produced by the training resorted to by pugilists, in order to get rid of superfluous fat, and give their limbs firmness, suppleness, power of stroke and that hardness of muscle which renders them insensible of blows.

All these effects come under the same laws, and are due to the same cause, namely, a properly regulated system of diet, the grand modifier of constitutions, of individuals and of species themselves; and if I limit myself to these remarks it is because, after having pointed out the extremely simple laws which regulate the production of animal substance, and having shown their connection with agricultural interests, I feel that I should be carried out of my own domain if I endeavoured to follow in detail the application of practical facts that I have not been able to check by personal experience. I will therefore content myself with saying that operations with cattle may either be independent attempts at agricultural speculation, in which case the principles of feeding we have laid down are equal to all the exigencies of the enterprise; or, as is more generally the case, live stock may enter into the lease of a farm on the half-profit system, and form in some sort a part of the plant of the farm.

There is always one fact of pre-eminent importance, viz., the necessity of abundantly manuring the grassland, and indeed all lands devoted to the growth of fodder. Now if it has been proved that farming is profitable only when aided by the use of chemical manures, why not put grassland upon the same system as arable? From a field that yields with difficulty 3,520 lbs. of hay per acre, it is possible, by the addition of chemical manure, costing from 1*l.* 12*s.* to 2*l.*, to obtain 7,040 lbs.

This addition of chemical manure is the first condition of success and the assured means of profit.

I am therefore right in telling you that cattle-raising will, like agriculture itself, owe its greatest progress to the doctrine of chemical manures, and that animal manure will not command a price commensurate with its richness and value until the high-farming system is extended to grassland.

This must be my reply to those who accuse me of proscribing the use of farmyard manure.

It has been well said that we cannot change the nature of things. Facts are imperious and inflexible in their affirmations. When the system of culture seeks to draw everything from the soil, both manure and crops, all the yields are feeble

and there is no profit; and when the yields are small the cattle are badly fed and are a certain source of loss. With chemical manure all this is changed. If, then, we adopt the use of manure from outside, at one stroke the price of fodder is lessened, the cost price of cereals diminished—the crops to be sent to market are more considerable, and the animals being better nourished the manure is of better quality, and its price advances according to the rate at which its richness increases. The advance in the price of meat during the past thirty years, joined to the increased demand for it, appears to me to be favourable to the extension of its production.

When the breeding of the cattle has been made remunerative and occupies a higher place in the assessment of farm products, an immense benefit will be obtained. The amount of activity that each one of us has to furnish is triple—at least—that of our forefathers; and in order to sustain this increased nervous energy it is necessary that our food itself should be improved. To show how pressing this necessity is it will be sufficient to state that from 1847 to 1862 the price of meat rose from 25 to 45 per cent., and from 1847 to 1873 from 40 to 70 per cent.

Progressive Increase in the Price of Meat since 1847.

Year	Price per lb.			Price per lb. of meat supplied to hospitals
	Beef	Veal	Mutton	
	<i>d.</i>	<i>d.</i>	<i>d.</i>	<i>d.</i>
1847	6·06	6·54	5·45	4·45
1848	...	...	4·36	4·36
1849	3·92	5·26	4·39	4·40
1850	3·78	4·67	4·45	4·25
1851	3·60	4·58	4·36	4·03
1852	3·74	5·11	4·38	4·03
1853	4·58	5·62	5·26	4·53
1854	5·34	6·10	5·65	4·97
1855	5·60	6·54	6·58	5·01
1856	5·73	6·58	6·47	5·23
1857	5·56	7·06	6·62	5·14
1858	5·34	6·66	5·56	4·97
1859	5·30	6·88	6·32	4·36
1860	5·45	6·66	6·41	4·84
1861	5·57	7·06	6·41	5·01
1862	5·62	6·76	6·19	4·97

Year	Price per lb. in provision markets of Paris				Price per lb. of meat supplied to hospitals
	Beef	Cow beef	Veal	Mutton	
	<i>d.</i>	<i>d.</i>	<i>d.</i>	<i>d.</i>	<i>d.</i>
1863	5·62	5·15	6·93	6·19	5·19
1864	5·62	5·15	6·93	6·31	5·23
1865	5·53	4·89	7·05	6·19	5·23
1866	5·70	5·15	6·70	6·50	5·40
1867	5·95	5·62	7·63	6·76	5·62
1868	5·91	5·45	7·58	6·67	5·50
1869	5·95	5·41	7·27	6·28	5·50
1870 ¹	5·99	5·58	7·58	6·76	5·54
1871 ²	6·30	5·88	8·55	7·20	6·89
1872	6·78	6·30	8·55	7·73	6·15
1873	7·70	7·24	7·97	8·77	7·85

In summing up from 1847 to 1853 and 1862 the increase has been :—

	Per cent.
Meat supplied to hospitals of Paris	12
Meat sold in provision markets of Paris	25
Meat sold in provision markets in the Departments	35
Meat valued where grown (agricultural inquiry)	45

But in 1847 and 1873 the increase has been :—

	Rate of increase Per cent.
Beef	70
Cow beef	80
Veal	40
Mutton	55
Meat supplied to hospitals	70

Is not the above a manifest proof that our production is insufficient? The number of our population, which is retrograding in forty departments, is also a proof of this. Well, how under the old system are we to increase our herds if the production of fodder is not increased in the same proportion? We must look forward to a continued increase in price for the people—an increase of distress, and to an uncertain future. How in the face of the figures I have just given will the working-man be able to live if the price of meat continues to progress in the same ratio during the next ten years?

But this digression into a new channel should give rise to no false construction. I still maintain that cattle are not

¹ The seven first months.

² The seven last months.

absolutely necessary to agriculture. The rôle to be assigned to them is not a question of principle but simply one of convenience, regulated entirely by the profit that it gives. The first question which has to be considered is this: In the system of culture where live stock are the only source of the manure employed, it is of the utmost importance to consider how far they figure in the amount of capital engaged, to what risks this capital is exposed, what profit it gives and how it is produced.

The study to which we are devoting ourselves requires the greatest attention, for it is by the aid of real calculations that practical facts, whose authenticity is beyond dispute, are established.

And now having fully discussed the question of feeding live stock, we will consider them from a financial point of view, and I will endeavour to show by the aid of figures the place assigned to cattle in an experiment made for the sole purpose of producing only animal manure.

I will quote from experiments made at Bechelbronn, so justly celebrated for being the place where M. Boussingault gained his incontestable reputation.

On the farm of 275 acres 150 acres were occupied by grassland.

	Acres
Arable land	125
Grassland	150

The first conclusion we draw is that if the system has merit it is certainly not that of simplicity, since in order to maintain the fertility of 125 acres of land it is necessary to have a cumbersome addition in the form of 150 acres of grass besides stabling for cattle, &c.

Does the system counterbalance this disadvantage by the great profit it secures? No; for with from 1,500*l.* to 1,600*l.* of capital, only 133*l.* 6*s.* 5*d.* profit is obtained. This you can readily see is a poor result. This profit was produced by the sale of vegetable commodities to the amount of 441*l.* 8*s.* But in order to ensure the continuance of the presumed source of profit, it is necessary to obtain as a parallel 570*l.* 15*s.* 3*d.* of animal produce which only figures in the account of the experiment as an ordinary item. Consequently the greater part of the capital is found to be absorbed by this part of the service which gives no profit, for to this 570*l.* 15*s.* 3*d.* that I have just indicated must be added the value of the animals, which cannot be less than 520*l.*

<i>Dr.</i>			<i>Meadow.</i>			<i>Cr.</i>		
	£	s. d.				£	s. d.	
Rent of land . . .	216	8 0	183 tons 14 cwts. of hay					
Labour	96	12 5	consumed by cattle, at					
Profit	25	4 7½	1l. 8s. 9½d. per ton .	264	9 0½			
			33 tons 11 cwts. of hay					
			sold, at 2l. 4s. per ton	73	16 0			
	£338	5 0½				£338	5 0½	

Total Profit.

	£	s. d.	
Vegetable produce	118	9 0½	
Live stock, <i>nil</i>			
Meadow	25	4 7½	
	£143	13 7½	

In what follows I have had constant recourse to condensed balance-sheets based upon this model, and in which the general results are more easily followed and discussed.

FIRST CONDENSED BALANCE-SHEET OF THE FARM AT BECHELBRONN, THE MATERIALS USED BEING CALCULATED AT COST PRICE.

A. Vegetable Produce.

<i>Dr.</i>			<i>Cr.</i>		
	£	s. d.		£	s. d.
Rent	180	0 0	Produce sold	440	19 1½
Labour	213	12 4	„ consumed	217	15 10½
710 tons of manure, at					
4s. 2d. per ton	147	18 4			
Balance	117	4 4			
	£658	15 0		£658	15 0

B. Live Stock.

Food	476	9 2½	Animal produce	519	3 2
All other charges	242	17 0	Days of work	52	6 1
			710 tons of manure, at		
			very nearly 4s. 2d.		
			per ton	147	16 11½
	£719	6 2½		£719	6 2½

C. Meadow.

Rent	216	8 0	183 tons 14 cwts. of hay		
Labour	96	12 5	consumed, at 1l. 8s.		
Balance of profit	25	4 7½	9 d., cost price	264	9 0½
			33 tons 11 cwts. of hay		
			sold, at 2l. 4s. per ton	73	16 0
	£338	5 0½		£338	5 0½

Sources of Profit.

	£	s.	d.
Cultivation	117	4	4
Meadow hay sold	25	4	7½
	£142	8	11½

I admitted that the entire amount of profit was due to culture in order to give greater simplicity to my explanation, but you can see that the grassland contributes one-fifth by the sale of hay, which reduces the profit by so much (one-fifth) and gives greater force to the criticisms which we have been able to make upon the system. But this is not all. This account, which is apparently exact, is, nevertheless, an illusory one. The straw and forage are given to the animals at cost price, an arbitrary and defective method of book-keeping against which I have not ceased to protest, with the greatest energy, since 1867. To support my opinion I have quoted the example of distilleries and sugar manufactories. Do they reckon beetroot at cost price? No. Why then proceed otherwise with respect to stables? If you make this rectification, which indeed it is impossible to avoid, instead of gaining a profit of 108*l.* the culture account will, on the contrary, show a loss of 21*l.* 4*s.*, and, by a reversal easily understood, the grassland becomes the source of all the profit. As for the cattle, in the precarious and badly devised system of feeding under which they are placed, they become an encumbrance. One thing that cannot escape you is that the manure, which in the first account was estimated at 4*s.* 2*d.* per ton, now appears at 11*s.* 10*d.*, that is to say at, at least, 2*s.* 4*d.* above its real value. We will now, in a fresh account, sum up the results of the experiment rectified in the manner I have just shown, and afterwards we will consider the lessons which may be drawn from it.

SECOND BALANCE-SHEET, THE MATERIALS CONSUMED
BEING RECKONED AT THE MARKET PRICE.

A. Vegetable Produce.

<i>Dr.</i>				<i>Cr.</i>			
	£	s.	d.		£	s.	d.
Rent	180	0	0	Sales	440	10	9½
Labour	243	7	3	Food consumed	383	17	7
710 tons of manure, at 11 <i>s.</i> 10 <i>d.</i> per ton	420	1	8	Loss	19	0	6½
	£843	8	11		£843	8	11

B. Live Stock.

<i>Dr.</i>				<i>Cr.</i>			
	£	s.	d.		£	s.	d.
Food	791	12	5	Animals fed	519	3	2
All other charges . .	242	17	0	Days of work	95	4	7
				710 tons of manure, at			
				11s. 10d. per ton . .	420	1	8
	£1,034	9	5		£1,034	9	5

C. The Meadow.

Rent	216	8	0	183 tons 14 cwt. of			
Labour	107	0	8	hay consumed, at			
Balance	154	8	1	2l. 4s. per ton . . .	404	2	9
				33½ tons 10 cwt. of			
				hay sold, at 2l. 4s.			
				per ton	73	14	0
	£477	16	9		£477	16	9

The balance of the farming account, I repeat, shows a loss of 19l. 0s. 6½d. That is easily explained, for the manure figures at 11s. 10d. per ton, when it is worth only from 7s. 11d. to 9s. 6d. per ton. But besides the manure being too dear the quantity produced is too small to ensure good crops.

But we know that it is only high-farming results that are remunerative. If the manure is insufficient or the price is too high, there is no profit. From the fact that the grass-land yields a profit and that it receives no manure, is it not evident that this special form of manure is not an imperative condition of success? On the other hand, since there is a profit, is it not a proof that the grassland receives more manure by irrigation than the arable land receives from the animal manure given to it? The conclusion is then forced upon us, that in order to secure a profit the land must be better manured and recourse must be had to chemical manures. Let us go back and examine the items of the account. You could not fail to remark that in the new account expenses of all kinds are found to be greatly increased. This is inevitable. From the moment that we quit the arbitrary and fantastic and calculate the cost of forage, straw, &c., at their real value, the price of manure rose from 4s. 2d. to 11s. 10d., and the total charges under this head from 147l. 18s. 4d. to 420l. 1s. 8d.; this is the explanation of the loss that I have already noticed. The farming charges are themselves subject to a marked increase, but this time the increase of expenditure is balanced by the high price put upon the day's work of the yokes of oxen with which the account of the animals is credited. This rigorous manner of keeping accounts is hardly consonant

with the habits of the agricultural world, but besides possessing the merit of banishing fiction it has the advantage of putting the farm accounts in harmony with the economical reality of surrounding circumstances. However, in spite of their interest, these rectifications have only a secondary importance. The important and unexpected fact brought to light by this balance-sheet is presented to us by the grassland. Instead of continuing to figure in the account simply as an item of expense, the grassland, on the contrary, becomes the source of all the profit; and for all that the hay is only reckoned at 2*l.* 4*s.* per ton. When all these rectifications are effected the final result is not changed, the profit obtained is always about 142*l.* 5*s.* 2¼*d.* Before this certainty will you take objection to my reasoning—that in the main you find it indifferent because to you all this seems only like playing with figures? Be careful not to yield to this temptation. What, indeed, does the first account say? That the arable land gave a profit, whence the conclusion that the soil was sufficiently manured. You need not make yourself uneasy; nobody asks or desires you to do better. Increase the cattle? It is not to be dreamt of. The grassland occupies more of the soil than the cultivated portion which is the source of all the profit. Under the mirage of an illusion like this you will, therefore, continue the traditions which have been handed down to you.

You will then continue to produce :—

20 bushels of wheat per acre
4 tons 16 cwt. of potatoes per acre
10 tons 8 cwt. of beetroot per acre

What does the second account say? That the manure costs more to produce than it is worth; it says, moreover, that the soil is not sufficiently manured. Is such a situation without remedy? We have one at hand which will change all that. Procure manure from outside, manure both grass and arable land more abundantly, raise the produce of all cultures indiscriminately.

The first account is a sedative which gives a false security. The second account, on the contrary, is a spur which urges us on and excites us to do better. Which ought we to prefer? There is no need to hesitate long. In such a matter your adhesion must not be limited by a paralytic decision; the account shows a constitutional defect in the machinery of cultivation; there must therefore be no hesitation, but haste must be made to remedy the evil.

Profiting by the research of science in the employment of

chemical manures, we must give to the grassland, at a cost of 1*l.* 12*s.* per acre, superphosphate, nitrogen, potash, and lime. The result is immediate, sudden, and almost magical, for everything gains thereby, both grass and arable land. Judge for yourselves by this third account:—

THIRD BALANCE OF THE FARM AT BECHELBRONN, SUPPOSED TO BE SUPPLIED WITH A MIXTURE OF ANIMAL AND CHEMICAL MANURE, THE PRODUCE CONSUMED BEING RECKONED AT THE MARKET PRICE. THE LIVE STOCK ARE BADLY FED.

A. Vegetable Produce.

<i>Dr.</i>				<i>Cr.</i>			
	£	s.	d.		£	s.	d.
Rent	180	0	0	Sales	662	15	1
Labour	283	18	5	Vegetable produce consumed	383	17	7
710 tons of manure, at 11 <i>s.</i> 10 <i>d.</i> per ton	420	1	8	Vegetable products for soil, and for live stock	191	18	10
Chemical manures	240	0	0				
Profit	114	11	5				
	<hr/>				<hr/>		
	£1,238	11	6		£1,238	11	6

B. Live Stock.

Food	791	12	5	Animal produce	518	9	2
All other charges	242	17	0	Work done by animals	92	4	7
				710 tons of manure, at 11 <i>s.</i> 10 <i>d.</i> per ton	420	1	8
				Loss	3	14	0
	<hr/>				<hr/>		
	£1,034	9	5		£1,034	9	5

C. The Meadow.

Rent	216	8	0	183 tons 14 cwt. of hay for use	404	2	10
Labour	124	17	3	250 tons, for sale	551	10	9
Chemical manure	200	0	0				
Profit	414	8	4				
	<hr/>				<hr/>		
	£955	13	7		£955	13	7

Total Result.

	£	s.	d.
Profit on vegetable produce	114	11	5
„ meadow	414	8	4
	<hr/>		
	£528	19	9
Loss on live stock	3	14	0
	<hr/>		
Net profit	£525	5	9

The improvement is considerable. In fact, notwithstanding an increased expenditure of 240*l.*, this expense having been

entirely incurred by the purchase of manures of certain efficacy, the culture account no longer shows a loss of 21*l.* 4*s.* but a profit of 114*l.* 11*s.* 5*d.*, which proves most positively the truth of the proposition which may be raised to the rank of an axiom, viz., that, in order to be remunerative, farming culture requires, above all other things, that we should give to the soil the entire amount of fertilising agents that the plants are able to utilise. It is only thus that the crops are abundant; only thus that they are a source of assured profit. But, besides this foremost lesson, a thorough examination of the account will disclose a flaw in the working of the farm which it is urgently necessary to remedy. The cost of animal manure is decidedly too great. At 11*s.* 10*d.* per ton it is at least 2*s.* 4*d.* above its real value.

What is the cause of this excessive cost? There is only one—the cattle are imperfectly fed. Cattle raisers of high merit affirm that in fixing the feeding of animals according to certain rules, the operations with cattle leave the manure as a profit, which would raise the profit at Bechelbronn from 133*l.* 6*s.* 5*d.* to 536*l.* 16*s.* 10*d.*¹

Without denying the possibility of such a result I deem it prudent to give it under slight reserve. M. Kühn, whose authority is unquestionable, affirms that when the precepts I shall presently put before you are applied to the feeding

¹Calculation of the operation of fattening carried on at Haningen, near Cologne, under the direction of M. Eisben. (See Kühn's *Engraisement des Bêtes à l'Engrais*.)

	£	s.	d.
Purchase of 240 oxen, at about 15 <i>l.</i> 17 <i>s.</i> 7 <i>d.</i>	3,811	18	0
Stable charges	63	0	0
Veterinary surgeon, &c.	3	6	9
General charges	47	10	0
Labour	25	16	0
19,200 daily feeds, composed of—			
Oil-cake, 24 tons	149	11	0
Dry clover lucern, 48 tons	144	0	0
Bruised wheat and bran, 22 tons 7 cwts.	358	19	8
Salt	8	7	8
Raw colza oil	10	11	6
Distillery waste, 10 cwts. per day fresh, or 8 cwts. for 19,200 feeds	384	0	0
Straw and chaff, at 22 lbs. per head per day, at 1 <i>s.</i> 1 <i>d.</i> per cwt. for 19,200 feeds	288	0	0
	£5,295	0	7
240 oxen sold, after eighty days' feeding, at about 22 <i>l.</i> 2 <i>s.</i> 2 <i>d.</i> per head	5,406	13	5
	£111	12	10

or a profit of, say, 9*s.* 3*d.* per head, with the manure to the good.

of animals, the gain above the results obtained by the old method is 1s. 2½*d.* on every hundredweight consumed.

Well, the consumption at Bechelbronn being 18 tons 7½ cwt., there would, according to M. Kühn, be an increased product on the animals of 110*l.* 4*s.* 5*d.*, which brings the price of manure down from 1*l.* 10*d.* to 8*s.* 10*d.*, its real value; but this is not all, for by a reaction easily foreseen, the culture account is likewise affected by this reduction, so that the profit rises from 11*l.* 1*s.* 7*d.* to 22*l.* 6*s.* 5*d.*, which leads us to the fourth balance.

FOURTH BALANCE OF THE FARM AT BECHELBRONN, WHICH IS SUBMITTED TO A MIXTURE OF ANIMAL AND CHEMICAL MANURE. THE COMMODITIES CONSUMED ARE RECKONED AT MARKET PRICES.

A. Vegetable Products.

<i>Dr.</i>					<i>Cr.</i>			
	£	s.	d.		£	s.	d.	
Rent	180	0	0	Vegetable produce sold	854	13	11	
Labour	283	18	5	„ „ consumed	383	17	7	
710 tons of manure, at 8 <i>s.</i> 10 <i>d.</i> per ton	313	11	8					
Chemical manure	240	0	0					
Profit	221	1	5					
	<hr/>				<hr/>			
	£1,238	11	6		£1,238	11	6	

B. Live Stock.

Food	791	12	5	Animal produce	628	13	7
All other charges	242	17	0	Work done	92	4	7
				Manure, at 8 <i>s.</i> 10 <i>d.</i>	313	11	3
	<hr/>				<hr/>		
	£1,034	9	5		£1,034	9	5

C. The Meadow.

Rent	216	8	0	183 tons 14 cwt. of hay used	404	2	10
Labour	124	17	3	250 tons of hay sold	551	10	10
Chemical manure	200	0	0				
Profit	414	8	5				
	<hr/>				<hr/>		
	£955	13	8		£955	13	8

Profit on vegetable produce	£	s.	d.
„ meadow	221	1	5
	414	8	5

£635 9 10

You see that the account of the animals balances with an insignificant profit. In these circumstances it is, however, an advantage to foster the growth of the animals,

because the stables pay for forage at market price, and notwithstanding this high price, the manure only amounts to 8s. 10d. per ton, its real value.

Here a new difficulty presents itself. If the increase of products given by the cattle instead of rising from 110l. 4s. 9d., attains 190l. 4s. 9d., how will it be necessary to settle the account? Will it be better to reduce the price of manure to a corresponding value? No; the manure must be kept at a price of 8s. 10d. per ton, which corresponds to its richness, and the excess of produce must be carried to the credit side as profit. The account will then be entered as follows:—

The Live Stock.

<i>Dr.</i>				<i>Cr.</i>			
	£	s.	d.		£	s.	d.
Fodder	791	12	5	Animal products . . .	708	13	7
Expenses of every nature	242	17	1	Day's labour	92	9	4
Profit as balance	80	5	1	710 tons of manure, at 8s. 10d. per ton . . .	313	11	8
	£1,114	14	7		£1,114	14	7

In order to be consistent with these principles I ought in the second budget of Bechelbronn, where the manure is estimated at 11s. 10d. per ton, to have proceeded in the same manner, viz., reckon the manure at 8s. 10d. per ton, and place as surplus to the credit of the animals thus:—

The Cattle.

<i>Dr.</i>				<i>Cr.</i>			
	£	s.	d.		£	s.	d.
Fodder	791	12	5	Animal products . . .	518	9	7
Expenses of every kind	242	17	1	Day's work	92	9	4
				710 tons of manure, at 8s. 10d. per ton . . .	313	11	8
				Loss	109	18	11
	£1,034	9	6		£1,034	9	6

I have not hitherto done so, in order that you may the more readily perceive how, according to agriculturists, the losses on cattle are unwittingly made to appear as the result of cultivation. So that you may better appreciate the value of the changes that these several accounts reveal, and mark in a more striking manner the progress to which they correspond, I need only place the results before you thus:—

	Annual profit		
	£	s.	d.
Culture with farm manure only, the cattle poorly fed . . .	142	5	2½
Culture on system of mixture of farmyard and chemical manures, the cattle poorly fed	525	5	9
Culture on system of mixture of farmyard and chemical manures, the cattle well fed	635	9	10

Then, as the agricultural question has two important ends to attain, viz., the interest of the producer who craves a profit, and the public interest which requires abundant crops in order that the people may live cheaply and well, let us put opposite this increase of profit the increase in value of the crops themselves:—

Gross Value of Crops comprising Animal Products.

	£	s.	d.
Culture with farm manure only, cattle poorly fed . . .	1,914	11	9
Culture on system of mixed animal and chemical manure, the animals poorly fed	2,805	3	5
Culture on system of mixture of animal and chemical manures, the cattle well fed	2,915	7	10

You see by this comparison that if high-farming yields are the most remunerative the profit produced by culture is, on the whole, greater than that given by cattle; therefore, how far from judicious it is to make culture subordinate to cattle in agricultural operations.

The effect of an introduction of chemical manure has such great practical advantages that to pass from the profitless to the profitable system I have been satisfied not to admit the realisation of excessive yields, but to hold to the average crops which have been confirmed by more than six thousand testimonials from all parts of the country. What is it then that I have in fact presupposed? That the yield of wheat increases from 20 bushels per acre to 30; potatoes from 4 tons 16 cwt. to 7 tons 4 cwt.; beetroot from 10 tons 8 cwt. to 16 tons.

But the information gained from the last account does not stop there. Besides the increase of profit a new feature is produced in the organisation of the farm, viz., a great abundance of forage and straw. What is to be done with it? You have the choice of three different solutions to this question. Are you near a large town? No solution can be equal to the sale pure and simple.

Are you unable to dispose of your forage, and have only a limited capital at command? Reduce the surface devoted to grass and land, and give more attention to growing by means

of chemical manures vegetable products used in manufactures.

A third solution remains, which under certain conditions may take precedence of the first two, viz., increase the live stock. Of these three solutions, which is the best? It is impossible *à priori* to say which.

The situation of the estate, its proximity to or its distance from large populous centres, and the means of transport are some of the conditions that must be taken into consideration, for they often suffice to give the pre-eminence to one or other of these three solutions.

It will not, however, escape you what unlooked-for resources grassland cultivated on the high-farming system by the use of chemical manure might contribute to a farm on which the rearing of cattle would be remunerative.

The production of forage at Bechelbronn, when left to its own resources, is about 18 tons $7\frac{1}{2}$ cwts. per annum,¹ the consumption of which produces 710 tons of manure; grown with the aid of chemical manure, the grassland passes from this small yield to 42 tons 9 cwts., which gives 1,600 tons of manure yearly at the price of 8s. 10d. per ton, and thanks to the mode of feeding, a profit of 150l. 8s. 10d. upon the animals themselves.

A fifth condensed balance-sheet might easily be drawn up to show the last change in the method of managing the farm; but I shall not place one before you, because I do not possess any sufficiently exact data as to the yield of crops under these new conditions, and because on such important questions all hypothesis must be abandoned; but what I have said on the subject will be sufficient to settle the question of principle and to show you that not to manure meadow land is as great a mistake as to leave cereal crops unmanured.

You may be tempted to oppose to this advice the results of the various industries which provide pulps, beetroot pulp for example, and to pride yourselves on the advantages attending them. But this case instead of invalidating the rule I have just laid down only confirms it, inasmuch as an increase of nourishment originating in industrial labour is practically equivalent to the introduction of chemical manure. But this is not all. Another effort must be made to throw every possible light on this question of live stock. I am in fact about to

¹ The real production of forage at Bechelbronn is 21 tons $12\frac{1}{2}$ cwts., of which 3 tons 5 cwts. is exported and sold. The quantity is, then, 18 tons $7\frac{1}{2}$ cwts.

prove to you that not only does farming on the old system with animal manure alone give neither profit nor security, but that it actually *exhausts the soil*. There can be no doubt of this, the exhaustion is slow, but it is real and continuous. And after the lapse of a century or two it inexorably shows itself by means of sad and formidable proofs, furnished by certain regions which were formerly flourishing but are now desolate.

This declaration is too serious a one for me to draw my proofs of it from exceptionable circumstances. I will not therefore quote the example of a small farm which is not manured, and in which the devastating action is manifest—I will rather draw my proofs from a privileged domain, and from an author who certainly cannot be suspected of partiality. M. Wolf has devoted much time to study and researches destined to define the most favourable conditions for the production and employment of manure. I take then from him the example of a farm situated on the other side of the Rhine, having a superficial area of $292\frac{1}{2}$ acres, of which $117\frac{1}{2}$ acres are devoted to crops for the market, 100 to permanent grassland, and 75 to artificial fodder. If I prove to you in good faith that on such a farm the fertility of the soil is impaired, will you deem my demonstration decisive? According to M. Wolf the farm loses in each year:—

Losses caused by Crops being used for Market Purposes.

	Vegetable products	Animal products	Total loss
	lbs.	lbs.	lbs.
Nitrogen	2,281	704	2,985
Phosphoric acid . .	1,003	264	1,267
Potash	657	158	816
Lime	145	242	387

The following, distributed over $192\frac{1}{2}$ acres, gives the expression of the loss sustained by the soil per acre per annum:—

$15\frac{1}{2}$ lbs. of nitrogen	$4\frac{1}{2}$ lbs. of potash
7 „ phosphoric acid	$2\frac{1}{2}$ „ lime

What resources are there to counterbalance the effect of this

loss? 100 acres of irrigated grassland, which gives in the main 4 tons of hay.¹

In which there is :—

	For the 100 acres	
	Tons	Cwts.
Nitrogen, 44·88 lbs.	2	1
Phosphoric acid, 14·04 lbs.	0	12 $\frac{3}{4}$
Potash, 58·08 lbs.	2	12 $\frac{3}{4}$
Lime, 46·64 lbs.	2	21 $\frac{1}{4}$

which, divided amongst the 192 $\frac{1}{2}$ acres of culture, gives in its turn per acre and per year in order to neutralise the loss due to exportation :—

	lbs.
Nitrogen	23 $\frac{3}{4}$
Phosphoric acid	7
Potash	30
Lime	24 $\frac{1}{2}$

If the nitrogen contained in the hay was all devoted to the benefit of the soil, the crops would gain yearly 8 lbs. per acre. But this is in reality far from being the case. The hay first serves to nourish the cattle, when one-third of the nitrogen is lost in the act of digestion. And this is not the only loss: the remaining two-thirds, in their turn, undergo a reduction, arising from the decomposition that animal excreta undergo in the manure heap, and this loss is not less than

¹ *Annual Losses sustained on a Farm of 292 acres, in which there are 100 acres of Meadow Land and 30 of Artificial Grass Land.*

	Nitrogen	Ashes	Potash	Lime	Magnesia	Phosphoric acid
Tons Cwts.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
12 0 wheat . .	576 $\frac{1}{2}$	490 $\frac{1}{2}$	153	16 $\frac{1}{2}$	60 $\frac{1}{2}$	227 $\frac{1}{2}$
13 2 rye . .	508	499 $\frac{1}{2}$	156	14	55	235 $\frac{1}{2}$
11 5 barley . .	376	540	119	11	45	178
8 10 colza . .	545 $\frac{1}{2}$	654 $\frac{1}{2}$	155	93 $\frac{1}{2}$	81 $\frac{1}{2}$	292 $\frac{1}{2}$
3 0 peas . .	275	184	76	9	14	68
4 0 milk . .	563	616	147	132	17	167
2 8 live stock.	141	246 $\frac{1}{2}$	9	110	2	91 $\frac{1}{2}$
Total . .	2,985	3,231	815	386	275	1,260

This loss, divided over the whole extent of arable land, gives per acre and per year :—

Nitrogen, 17 $\frac{3}{4}$ lbs. ; ashes, 19 $\frac{2}{5}$ lbs. ; potash, 5 lbs. ; lime, 2 $\frac{1}{4}$ lbs. ; magnesia, 1 $\frac{1}{2}$ lbs. ; phosphoric acid, 7 $\frac{3}{4}$ lbs.

(Emile Wolf, *Etudes pratiques sur le Fumier de Ferme*, page 108.)

one-third of the original quantity. The result is that the soil receives at most only 8 lbs. of nitrogen per acre yearly.

We know by experience that in giving to the soil the moiety of nitrogen contained in the crops the soil is not impoverished. The loss being 16 lbs. and the restitution 8 lbs., we are thus enabled to admit that the two amounts balance, that there is no loss and no gain, but stagnation. With phosphoric acid it is not the same, the soil loses 7 lbs. per acre, the grassland returns 7 lbs. ; but when the loss by rains is determined, the proportion of phosphoric acid which passes into the state of ferric phosphate and aluminic phosphate, both of them inactive compounds,¹ constitutes a real loss, the effect of which must in the long run be severely felt.

It is true that the soil receives notably more potash and lime than it has lost, but by reason of the deficiency of nitrogen and phosphoric acid the increase of these two products is of no avail. With farmyard manure alone farming is fatally arrested at the outset, and if the results which belong to this system are so far removed from the high-farming system the explanation is at once apparent.

You will observe how carefully all exaggeration has been avoided. This result was not obtained on a poor farm, but on one remarkable for the vigour of its constitution. It is a grievous fact that nitrogen and phosphoric acid should be deficient, when it is well known that they specially regulate the production of cereals.

In order to remain faithful to the moderate course we have adopted, suppose that the part devoted to meadow land was rather less, or that out of the 100 acres they had 25 or 30 not irrigated, being what we call high lands, and requiring, as is generally the case, to be manured, the injury suffered by the property would in a very short time lead to a decrease in all the crops.

If I had wished to give a more striking character to this demonstration I could have taken a small farm as an example, but I have not done so. The estate quoted is one on which, strictly speaking, the losses are only threatened, and I invite you to meditate on the example ; see how well balanced is the constitution of the domain, and yet how precarious is the present, and how subject to inevitable deterioration the future.

To sum up. Generally speaking, what the soil of our old continent of Europe is deficient in is phosphoric acid and

¹ The inertness of ferric and aluminic phosphates is maintained, on the faith of recent trials, by Mr. T. Jamieson, F.C.S., Chemist to the Aberdeenshire Agricultural Association.

nitrogen. Hence the success obtained by guano. Nine times out of ten the introduction of phosphoric acid and nitrogen suffices to raise the yields of cereals and the greater part of the industrial crops. But do not lose sight of the fact that this success will be only for a time, and if you wish to grow crops of beetroot, potatoes or artificial grass, the necessity of potash and lime will soon be felt, and unfortunate will be the imprudent man who closes his eyes to this evidence.

If you wish to strengthen your means of action by the introduction of manure, begin with nitrogen and phosphoric acid, the nitrogen in the state of ammoniac sulphate or sodic nitrate: the phosphoric acid in a state of superphosphate. Then, in the second place, have potash in the state of potassic nitrate or chloride,¹ and lime in that of gypsum.

To those who reproach the doctrine of chemical manures with being the enemy of live stock, who say that it condemns and proscribes them, you will be able henceforth to reply that by it, and by it alone, are we able to produce cattle with profit and to obtain manure at a low price, for without the introduction of manure from without these two operations are evidently very expensive.

You now know, moreover, that the laws which govern plants are practically the same as those which govern animals; that plants and animals are in the same degree veritable machines, to which must be given all the raw material they are able to utilise; that to be parsimonious in this respect is the worst economy, since it is being unmindful of the law that ensures a profit, viz., a large production with few general expenses. This result is obtainable only in one way. Let the cattle be well fed. Manure the soil abundantly, following the rules that you already know. This can be thoroughly done only by the application of manure from outside indiscriminately to cereals and forage, to the crops needed for the stables as well as to those needed for the market; and this condition is, as you know, essentially one of the fundamental rules of the doctrine of chemical manures.

¹ Potassium nitrate is too expensive for use as a manure; kainit and potassium sulphate should be used.

LECTURE XV.

AGRICULTURAL INDUSTRY.

IN order to fill in the outline I have traced out for myself and throw light on the agricultural problem in all its aspects, I must explain what is understood by agricultural industries, so as to prevent the confusion that too often arises between industries that are connected with agriculture and those that directly belong to the soil. Practice, guided by its marvellous intuition, has outstripped theory, and it is this which gives increased interest to the results obtained, seeing that the facts it has brought to light confirm, as a general rule, what I have said relative to the employment of chemical manure. You know that Mathieu de Dombasle had annexed to the Institute of Roville a manufactory of agricultural implements, which brought him in large profits. Was this an agricultural industry in the strict sense of the word? Evidently not, because a manufactory of this kind has not and cannot have any connection with the cultivation. What, then, are the industries that merit the qualification of agricultural? Those which operate on the produce of a farm and are an indirect source of manure. For example, sugar factories, distilleries, starch factories, steeping-houses for hemp and flax, and, what may surprise you, the cultivation of the maritime pine.

Now distinct as these industries appear to us, they have, nevertheless, by the nature of their products or their method of action, a common character, which makes them one veritable industrial family; in fact all of them, however different they appear, tend, though by different ways, to the same end, namely, to restrict the exportation of vegetable products to those which cause no loss to the soil. Our business is now to define the character of these remarkable industries and to disclose the common characteristics which render them subject to the same laws.

I will take distilleries as my first example. To what is their function reduced, regarding them from an agricultural point of view? To consume beetroot, to export alcohol and to provide pulp for live stock; that is to say, a distillery is

equal to an increase of meadow land, since it procures an increase of food for the animals.

On the other hand, the industrial product that we export is alcohol. Now I must add that the sale, for exportation, of this product, however extended it may be, will not in any way lessen the fertility of the soil. But how can we have a considerable exportation without real loss? One word will suffice to explain this apparent contradiction. Rain-water and carbonic acid contained in the air cover all the cost, provide all the raw material; for, as you know, alcohol contains nothing but carbon, hydrogen and oxygen. Practical farming confirms the fact that distilleries contribute to the amelioration of the soil, and science explains why.

The fact is certain, the explanation is not less so, and what we have just said of alcohol is equally applicable to sugar, from which alcohol is derived by means of fermentation; the exported product is different, but the chemical composition is analogous.

I extend the same remark to starch factories. Here the basis of manufacture is not beetroot but potatoes; the exported product is neither sugar nor alcohol but starch. But the composition is analogous, if not identical.

In starch, as in sugar and alcohol, there is only carbon, hydrogen and oxygen. Nothing, therefore, is abstracted from the soil, and we have a residue in the form of pulp, which, it is true, is inferior to that of beetroot in point of nutritious value, but which can, nevertheless, be used as food for live stock.

The manufacture of hemp and flax, which is carried out with such perfection in England and Ireland, belongs to the same class.

Chemically speaking, flax and hemp are composed of three distinct parts, the textile fibre, the stalk, properly so termed, of which the textile fibre forms the exterior envelope, and a gummy, resinous matter which adheres to it. The object of the steeping or retting process is to detach the textile fibre from the stalk proper, and at the same time to deprive it of the gummy, resinous matter which soils it and impairs its quality. If the steeping water be utilised to feed pigs,¹ or simply as an addition to the liquid muck of the farmyard to water the grass or the manure heap, the exportation is limited to the steeped and heckled textile fibre, the soil still loses nothing, because the cellulose of the finished product

¹ The steeping water is offensive in its character, and without previous experiments cannot be recommended as food for pigs.

admits into its composition only carbon, hydrogen and oxygen. That the air was a marvellous renovator of the soil was proved with admirable penetration by practice at a time when people were ignorant of what the atmosphere furnished to plants.

But from this point of view science has long since pointed to a solution more simple and more complete than any preceding it, which is based upon the culture of oil-yielding plants. Notwithstanding the difference between their physical state and their common properties, oils admit into their composition, like sugar, alcohol, starch and textile fibre, nothing but carbon, hydrogen and oxygen. Consequently, instead of selling the oleaginous seed the oil is extracted on the farm itself and sold, and the other parts of the plant being returned to the land, they will help to maintain the soil in a state of increasing fertility. Under this system the cake that the seeds leave after the extraction of the oil will be the principal manure. These cakes are in fact very rich in nitrogen, phosphates and potash. Dissolved in water we can by their aid prepare from them a sort of artificial urine, which, if thrown into the manure-pit, effects the disintegration of the haulm, husks and more especially the straw itself. But in order that this system should realise in practice the advantages that are indicated by theory, the whole of the oil must be extracted from the seed. After leaving the hydraulic press the husks contain from 6 to 8 per cent. of oil, which can be extracted by means of chloroform or by carbon bisulphide, or the light petroleum or coal oils. This process is not at all difficult. The apparatus is not costly. I will not, however, enter more into detail, it is enough for me to have pointed out the result. I will only add that instead of treating the seed in its entirety farmers should limit themselves to purchasing the husk, from which they can extract the remaining oil by means of carbon bisulphide. Thus treated, the husks used as manure effect a saving of at least 2*l.* 8*s.* per acre. Here are some figures founded on a crop of colza which will bear out this assertion :—¹

¹ I had fixed the terms of the theory I have just advanced in 1860, as is seen by the following extract from letters patent taken out on November 10, 1860 :—

“ WHY DO I TAKE OUT PATENTS ?

“ By my patent for the production of chloroform on a large scale, and by my patent of to-day for the extraction of oils, I have the ambition to create a new system of farming—a system of industrial farming—sufficient in itself to keep the soil in a high state of fertility without any other

PRODUCTS PER ACRE.

1. SALE OF THE NATURAL SEED.

	\pounds	<i>s.</i>	<i>d.</i>
38½ bushels, or 18 cwts. 0½ qr., at 18s. 9d. per cwt.	17	0	0

2. EXTRACTION OF OIL BY PRESSING (OLD SYSTEM).

18 cwts. 0½ qr. of seed, giving 35 per cent. of oil=711 lbs. of oil.

manure than the residue of the manufacture, of which the crops are the first principle, or raw material. I will explain myself more clearly. By the aid of chloroform—applied for the extraction of fatty matter—I wish to give to farmers the means of extracting the oil from their oleaginous seeds more completely and more economically than is done in oil-mills at present. In the future the farmer will export the oil, and not the oleaginous seed. After the extraction of the oil the husks and straw will serve to give back to the soil the productive agents it has lost. The whole of the useful agents will return to the earth, only a product that has no influence upon vegetation will be exported; oil, in fact, does not possess fertilising properties. Thanks to this system, the cultivation of colza and poppies (which are highly productive crops, but which greatly impoverish the soil) will, indeed, be more complete than in the case of beetroot.

“With beetroot the soil only receives a part of the nitrogen of the crop, namely, that which the animal excreta retain; the nitrogen that the animals assimilate, and which they breathe into the air, is lost to the soil. If we work beetroot in order to extract the sugar, or to transform it into alcohol, the greater part of the potash contained in the crops is still lost to the soil. In the case of oleaginous plants, none of these losses take place; the husks steeped in water contain almost all the nitrogen, phosphates, potash and lime carried off from the soil by the crop.

“This manure contains the elements of a new crop under a form most favourable to its assimilation by plants; we have no need to have recourse to animal digestion in order to prepare the manure, the facility with which the husks suspended in water are decomposed rendering this intermediate organ, the employment of which is most burdensome, absolutely useless.

“If, instead of employing the husks alone, we at the same time utilise the dead leaves of the crops, immersing them in water, with the addition of a portion of the husks, in order to favour their disintegration and decomposition, the culture of oleaginous plants will become more beneficial than theory conceives or art is able to realise, for the land will profit each year by the nitrogen drawn from the air by the previous crop, as well as by the useful minerals which are rendered accessible to vegetation by the disintegration of the constituent rocks of the soil.

(Signed) “G. VILLE.

“43 Rue de Buffon : Nov. 10, 1860.

“Patent for fifteen years, taken out Nov. 10, 1860, by M. G. Ville, is annexed.

“For the Minister by Authority,

“The Director of Home Commerce,

(Signed)

“E. JULIEN.

“Paris : December 18, 1860.”

Then :—

	£	s.	d.
711 lbs. of oil, at 2l. 9s. per cwt. . . .	15	11	0
1,260 lbs. of cake, at 6s. 3d. per cwt. . . .	3	10	9
	£19	1	9

3. EXTRACTION OF THE OIL BY MEANS OF BISULPHIDE OF CARBON
(NEW SYSTEM).

	£	s.	d.
914 lbs. of oil, at 2l. 9s. per cwt. . . .	19	19	10
1,058 lbs. of cake, at 6s. 3d. per cwt. . . .	2	19	6
	£22	19	4

Comparative Results.

	Produce per acre		
	£	s.	d.
1. Sale of natural seed	17	0	0
2. Extraction of oil by pressing	19	1	9
3. Extraction of oil by bisulphide of carbon	22	19	4
Difference in favour of extracting the oil by means of bisulphide of carbon	3	17	7

Plantations of resinous pines enter into the system of the cultivation that now occupies us. Those amongst us who have passed through Gascony know how marked the contrast is between the trees and plants of the district; the latter being meagre and stunted, vegetation is there represented by weeds and furze, the usual tenants of waste lands. But side by side we find the trees in a state of richest verdure and luxuriant health. Magnificent forests of resinous pines are to be seen, the trees of which are 25 or 30 feet in height; and we are led to ask, Why do the trees prosper where plants grow so badly? Because the trees—the maritime pine in particular—are more dependent for life upon air and water than plants are. But this is not all. When the pine has reached the age of fifteen years it is cut for resin in the following manner: Deep cuts are made in the lower part of the trunk, and the resin which exudes is collected into a hollow place scooped out at the foot of the tree. Each year from 12 to 14 cwts. of resin are thus exported, and experience proves that so far from being exhausted the land is always improving, because resin, like sugar, alcohol and oils, is only composed of carbon, hydrogen, and oxygen.

In order to extract sugar from beetroot a manufacturing plant is required, which does not cost less than from 30l. to 50l. per acre.

To utilise the pulp it is further necessary to have a large amount of live stock, which means a large investment of capital.

With agricultural oil mills the manufacturing plant is far more simple, and it is not necessary to keep cattle, as the husks can be used directly as manure.

In the Landes the manufacturing plant is more simple still, for we only need a hatchet, a shovel and a scraper, for the resin flows spontaneously from the tree. On the one hand we have manufacturing industry at its highest degree of power, while on the other it is rudimentary and almost pastoral. One acre of land planted with beetroot produces, as a rule, 16 tons of roots, from whence nearly 2 tons of sugar, worth at least 240*l.*, is extracted, giving to the State in France a revenue equivalent at least to its value. One acre planted with the maritime pine produced, on an average, each year, from 4 to 5 cwts. of resin, worth from 2*l.* 4*s.* to 3*l.* 8*s.*

	lbs.	lbs.
1. Solid resin	770 to	1,100
2. Liquid resin	352 „	440
	1,122 „	1,540

But do not let us disdain pine plantations. It is the industry of poor soils and of regions where the population is very scattered. Pines flourish without any outward assistance, the dead leaves returning to the earth all that the tree had taken from it. They enrich it even with nitrogenous compounds which are drawn from the air, and the decomposition of the leaves produces a sort of organic binding material, which in a certain measure replaces the clay of which the earth is devoid.

Notwithstanding this dissimilarity all these industries come under a common law, they are all based on the same fact. They only produce carbohydrates. But if practice is unanimous in testifying that the exportation of these matters in no way detracts from the fertility of the soil, it at the same time justifies and confirms one of the most essential principles of the theory of chemical manures. What have I said in the previous chapters? That it was useless to return carbohydrates to the soil, that it was an error to believe it necessary to give as manure all that the crops contained, and that those parts of the plants can be suppressed that have for their origin the air and the rain.

At first this proposition seemed to be totally opposed to practice, but only apparently so, for we find that we are able to export with impunity what the air and rain have given to the plant, that is to say, carbon, hydrogen and oxygen. These two propositions then say exactly the same thing under two different forms, giving to the principles that we

defend that degree of generality which belongs to natural laws.

This is why I attached a particular importance to fixing once for all the character of agricultural industries. Cultivation, meadow land, live stock and manufacture are now defined and each put in its proper place. You see how they attach themselves the one to the other, how they react the one upon the other, and the part that each one plays in the final result—profit.

To complete the picture and to give it the necessary prominence, I will make a thoroughly complete examination of one of these industries in order to show that culture and manufacture have interests which are easily reconciled, and also to point out how, through want of knowledge, conflicts which are prejudicial to both may arise.

I shall naturally take for my example the most important of all the branches of French agriculture, important both on account of the large capital it requires and from its unrivalled action upon the progress of agriculture in general. You will understand that it is to the manufacture of sugar from beetroot that I allude. What remembrances this plant brings back to us!—the Continental blockade; the struggle of the old world with new ideas; the advent of the steam-engine; manufacturing industry on a large scale appealing timidly to the system of anonymous associations of capitalists, which was shortly to become the source of so much private and public wealth. But whilst recalling these memories, we lose sight of the practical question that should alone affect and occupy us. I must here mention that though I am perfectly certain as to what I affirm on certain points, there are others on which I am still in doubt. I have for some years been collecting facts of great practical value. I am in possession of most important results; but there are a number of theoretical questions that embarrass me, and respecting which I still hesitate. If I wished to present to you a complete and incontestable theory of the economic production of sugar from plants generally, I should still have to wait and study deeply. I should silently pass over certain results that have great practical value in my eyes, although as yet they are incomplete.

Attaching themselves to the question of beetroot, there are two equally important interests that it is necessary to conciliate—the interest of the farmer and the interest of the manufacturer. To sacrifice one of these interests to the other would not only be unjust, but it would render any lasting solution impossible. It is necessary for the farmer to

have large crops. If the yield is under 14 tons of roots per acre, the cultivation of beetroot is not remunerative. The second interest, that of the manufacturer, is not less imperious. For him it is necessary that the beetroot should yield in the laboratory at least 12 per cent. of sugar, for under this amount little more than 4 per cent. can be extracted on a large scale, and at this rate there is no profit, so it is evident that he who deals with beetroot must obtain sugar enough to yield a profit.

If this result be not attained the works which have been set up at great cost cannot subsist; they must inevitably be shut up, and the farmer at the same time loses his market.

On the other hand, if the cultivator, in order to obtain beetroot of good quality, such as the manufacturer requires, sacrifice the yield and produce only a small crop, it is evident that it is not to his interest to take the beetroot to the works. To conciliate these contending interests an equitable arrangement must be arrived at: instead of looking at the question in the usual way, each party trying to set all the advantages to his side, the problem must be defined scientifically, and each must say to himself, We will work into each other's hands so that both will be able to benefit.

By pondering on these ideas, and after many experiments, I have found a method of obtaining beetroot of high quality and also abundant in crop. The theory of the result I possess only in part, but side by side with the theory is the fact, and that fact I am about to present to you.

What is it necessary to do in order to obtain large yields of beetroot? In the first place, to employ a manure containing large quantities of nitrogenous matter; this is a rigorous condition. Now, respecting the nitrogenous matter there are two very different cases to be considered.

The first of these cases is that in which the nitrogenous matter is immediately assimilable because it is entirely soluble; and the second where it is in a state of animal matter, which is not assimilable in its natural form, but only acts by the product of its decomposition.

In the first case we obtain beetroot of a superior quality, and in the second the beetroot is generally poor in sugar. In order to obtain a good crop of beetroot it is necessary to have nearly 176 lbs. of immediately assimilable nitrogen per acre.

If, instead of complying with this condition, we give the soil 440 lbs. of nitrogen in the form of stable manure, Flemish manure or refuse oil-cake, this nitrogen which is insoluble, and of which one part only acts after a time, has the inconvenience of continuing its action after the beetroot is almost

fully developed, thus causing the formation of leaves up to the last moment. This continued action, instead of enriching the root, takes from it, on the contrary, a part of the sugar it contains, and consequently impoverishes it. I repeat that if the beetroot puts forth leaves to the end of the season, the proportion of sugar is diminished. The first result, therefore, for which we are indebted to experience, is the following:—

In order to have a good crop of beetroot it is necessary to give it a large dose of nitrogenous matter; and to be of good quality, beetroot requires that the nitrogen should be in a soluble form. The beetroot then absorbs the greater part of it in six weeks, or two months before the term of its development, and at the end of the season it prevents the formation of leaves which, instead of enriching the root, causes it to lose a part of the sugar it contained.

You will notice that I am not propounding a theory; I am adhering simply to facts. I will further add that chemical manures are preferable to all others for beetroot: for nitrogenous matter use sodium nitrate or ammoniac sulphate, the effects of which can be regulated at will because they are entirely soluble; but when farmyard manure must be used it is advisable to apply not more than 8 tons per acre, burying it at the bottom of the furrows in the autumn, and giving as an addition to the farmyard manure a certain amount of chemical manure in the spring.

I again repeat that to be of good quality beetroot must, at the time of pulling, have attained its full development, and the leaves should have begun to turn yellow, to obtain which result $\frac{8}{10}$ of the nitrogen in the manure should have been absorbed.

The nature of the manure, the reciprocal relation of the substances composing it, and their degree of stability, have then a considerable influence both upon the amount of the crop and on the saccharine richness of the roots. When I commenced my experiments at Vincennes the ground on which the field was established turned out to have been formerly meadow land. The first year I obtained good crops of beetroot, but the roots only yielded in the average from 8 to 9 per cent. of sugar. The following years the crop kept up from 14 to 20 tons per acre, and the quality underwent a progressive amelioration which has not yet stopped, and now the roots from my crops yield as a rule from 14 to 16 per cent. of sugar.

The manufacturers of sugar all know well that the beet-roots grown with chemical manure are far richer than those grown with farm manure. Here is one testimony amongst

many, the value of which is increased by the position of the distinguished man from whom I borrow it ; one of the directors of Fives-Lille has obtained, on a farm in Normandy, with chemical manure, beetroot which yielded 15 per cent. of sugar, whilst with farmyard manure their richness only equalled from 10 to 11 per cent. This experiment was made during the years 1871 and 1872. Quite recently I have received a pamphlet from that most estimable and learned man, M. Pagnoul, Professor of Chemistry at Arras, giving an account of experiments of parallel crops fertilised with chemical and animal manures.

On the one hand, farm manure containing 440 lbs. of nitrogen in the insoluble state, whose action is founded upon the slow but continuous decomposition of the substances it contains, prolongs its action up to the time of gathering in the crop. The chemical manure, on the other hand, which can be absorbed almost immediately, acts strongly in the beginning, and very slightly at the end. What has been the result of this excellent experiment ? With farm manure we have obtained beetroot yielding 9 per cent of sugar ; with chemical manure it was increased to nearly 14 per cent. Thus two orders of facts have established the superiority of chemical manure for the culture of beetroot. On the one hand, the practice of the experimental field at Vincennes, which embraces a period of fourteen years, and on the other, the testimony of large growers, confirm in the main the results that have been obtained there.

We will look at the question a little closer and inquire what the increase of richness is which may be produced by the choice of manures and due application of the substances composing them. I believe it is not less than from 3 to 4 per cent. by weight of the roots ; and in a crop of 16 tons an increase of 3 per cent. in richness is equivalent to $9\frac{1}{2}$ cwts. of sugar, worth from 9*l.* 12*s.* to 11*l.* 4*s.* If we utilise only the half of this excess at the sugar factory, the result will still be very important. But does the choice of manures exhaust our means of action ? No. There is still another method not less efficacious than the first, and, like it, confirmed by practice, viz., the choice of the seed. A manufacturer who has made some very useful researches on the improving of plants by carefully selecting the seed has succeeded in obtaining beetroots yielding 14, 15, 16 and 18 per cent. of sugar. But these beetroots, though so rich in sugar, have their drawbacks, one being that they give only medium crops. Another is that they are forked, that is to say, the extremity terminates in four or five independent roots, which

retain a great deal of the soil. The washing of forked roots is such a difficult process in the factories that, notwithstanding their richness, they are almost always refused. On the other hand, the farmer cannot consent to produce such beetroot on account of the scanty yields, which never exceed 10 tons per acre, if, indeed, they reach this figure. Suppose that on 1 acre we obtain 8 tons of beetroot at 16s. per ton; that makes 6*l.* 8*s.* If we have expended 4*l.* 15*s.* in manure, next to nothing remains. But some people say that the wheat which succeeds the beetroot is the real source of profit, and that in truth part of the price of the manure should be placed to the account of the second year's cereals.

This amendment, which has some foundation, does not, however, remove the difficulty, and cannot be accepted as its solution. If the quality of the beetroot is only obtained at the price of an insufficient crop, it is an extra chance of loss, and seriously affects the poor farmer.

It is then an absolute necessity that we should obtain crops of from 16 to 18 tons of beetroot which is also rich in saccharine matter, so that we may be able to say to the manufacturer, "The beetroot we bring you is perfect, the shape is irreproachable, and it contains 15 per cent. of sugar, consequently you can afford to pay us its real value".

Under these conditions the manufacturer will, by purchasing, promote both his own interest and that of the agriculturist. It is necessary to satisfy both, otherwise the solution is incomplete.

We will now see how we must proceed for the improvement of the root in order to complete the effect produced by the manure. In the first place well-formed beetroot must be selected for seed, the irregular forms being rejected, as well as the very large or very small varieties. Between 2 lbs. 3 ozs. and 3 lbs. 4 ozs. in weight is the best sort. The first choice effected, a proper selection having been made, it is necessary to analyse each beetroot separately. To do this we take off a small portion of say 300 to 400 grains by means of a steel borer about a third of the distance down the root; the zone at this stage possesses the mean richness of the whole root. Below 12 or 14 per cent. of sugar a root is of no use for seed.

The slight laceration to which the roots are submitted detracts neither from their good preservation nor from the production of the seed, but it is necessary to keep them in a well-ventilated pit and thus avoid all desiccation. The seed thus obtained serves for the production of a crop, from which a new selection is made, paying attention this time to the

shape and weight of the roots only, and the seed resulting from this second generation is the true seed for the farmer. If you limit yourselves to using the same seed always, you will find that as the generations succeed each other the weight of the crop diminishes, and the root, which originally was perfectly formed, becomes forked. But there is one means of obviating this inconvenience, and that is to continue selecting fresh seed year after year. I repeat then, if you desire beetroot of a superior quality, it is absolutely necessary to renew the seed-bearing plant every two years. Thus only can the weight, the form and richness of the root be maintained to the desired degree.

When the time for getting in the crop is come, select the roots one by one, class them according to their degree of richness, eliminate all those of defective forms and all the small ones, reject the poor roots and keep as seed those of a high degree of richness and whose weight ranges from $1\frac{3}{4}$ lbs. to 2 lbs. 10 ozs.

With the seed of this first generation, we proceed to cultivate a crop with excessive care, remembering that it is the roots of this first crop that are wanted to furnish the farmer's supply of seed.

In the first place it is necessary that the soil should be well dug up so as to favour the action of the air and of frost, leaving it to face the winter in open furrows. In the spring it can be raised and levelled by good harrowing.

One essential precaution if we employ animal manure is to lay it at the bottom of the furrows when first put in. The immediate contact of the manure with the inferior layers, and the absorption by these layers of the soluble parts, realises the advantageous conditions of subsoil manures, to which I shall return in a moment. As for the chemical manure, it is necessary in the spring to spread it over the surface of the soil and harrow it immediately afterwards.

When the subsoil is heavy and the manure is unequally distributed in the upper layer the roots become irregular and forked.

I have said that beetroot obtained under these conditions serves for the production of the farmer's supply of seed, which is consequently the seed of the second generation; but side by side with the production of this it is necessary by rigorous selection to regenerate the type of the seed.

By proceeding in this manner we arrive at excellent results. The richness of the roots is exceptional and their shape irreproachable.

Here a most important practical question presents itself :

Can the work of selection be done by farmers ; are they able to undertake this amongst the cares and variety of work that are comprised in the management of a farm ? I do not hesitate to answer, No. In order that the result should be commensurate with the expenditure the production of the seed should fall on the sugar manufacturers, who are the most interested. What is necessary for that ? To annex to each factory a field, 25 or 30 acres, to produce seed of superior quality, and at the same time perfect the formula of manure. To this arrangement add the prohibition of animal matter as manure, or at least urge the necessity of employing it only in moderate doses, and the result will be to the common satisfaction of both manufacturer and cultivator, and a conciliation of interests will thus be brought about.

It is to this end that my efforts for the last six years have been directed. The gain obtained in a financial point of view may be ascertained by seeking the testimony of the manufacturers, who will probably tell you at first that they get almost nothing from beetroot. But if you inquire closer they will perhaps allow that they obtain 6 or 7 per cent. of sugar, the truth being that when the yield at the factory reaches 5 per cent. the result is advantageous.

We will, however, make a more moderate supposition. Suppose a factory uses every year the crop of 2,500 acres, which now is about the amount consumed by established factories. Let us further suppose that the beetroot supplied contains 10 per cent. of sugar, and actually yields to the manufacturer 5 per cent. Substitute for these roots which, when tested in the laboratory, contain 12 or 13 per cent. of sugar and yield in the factory 6 per cent., and you will have an extra profit of 1 per cent. In a crop of 16 tons there is an excess of 352 lbs. of sugar per cultivated acre, the increase in value being 3*l.* 16*s.* 9*d.*, and for the 2,500 acres that feed the factory an increase in production of 9,600*l.*

To show you the importance of the question now occupying us under all its aspects, we will suppose in place of an ordinary factory a grand central factory, flanked with seven or eight grating-houses, regular detached forts which protect it and feed it with all the juice extracted within a radius of three or four miles, like those connected with the sugar factories of Abbeville, Meaux and Coulommiers. In this case it is not 2,500 acres of culture that must be annexed to the works, but 7,500 acres at least, and the excess of receipts amounts to 24,000*l.* to 28,000*l.* Reduce these figures as much as the most scrupulous person could desire, and the result will still remain very important. Can you hesitate

then to follow the system by which it is obtained? I repeat that to guarantee a profit to the farmer the crops must realise at least 18 tons per acre; and to secure profit also to the manufacturer the roots must yield at least 12 per cent. of sugar in the laboratory.

Now this double result being obtained, how will the interest of both parties be served? Will the sugar manufacturer limit himself to measure the standard of all the lots of beetroot that are delivered to him? Evidently not, for when he knows that they are grown from the seed bought from himself and produced by him for the purpose, it will be quite sufficient for him to reject all roots weighing more than 2 lbs. 5 ozs., because beyond that weight their richness is notably diminished, or if he does receive them it will be at a reduction agreed upon beforehand.

But in order that the farmer should have confidence in the seed that is sold to him, the manufacturer must raise the buying price. Beetroot that yields 12 per cent. of sugar is worth 16s. 4d. per ton; above 12 per cent. it is worth 17s. 10d. at least.

To obtain this superior quality of seed each sugar factory should organise a special laboratory, and each year execute 8,000 or 10,000 analyses of beetroot. With the methods we now possess this work presents no serious difficulty, for children of ten or twelve years old can execute it with rapidity and certainty.

If it were a question of an academical treatise I would not propose this means; but if the analysis discloses 14, 14.5 or 15 per cent. of sugar in the root, we need not trouble ourselves with all the niceties that science demands, or that theory exacts from those who wish to formulate laws; from a practical point of view the fractions are of no importance, if the 14 per cent. that the analysis discloses is correct. Common-sense requires a just agreement between the proposed end and the means employed in order to arrive at that end. If we are desirous that the manufactories should receive beetroot yielding 13 or 14 per cent. of sugar, let us obtain this result, and a few fractions more or less are of no consequence. The above is, in my opinion, the method that ought to be followed. The principal point is the selection. It is necessary each year to prepare the seed for the following season, and by this selection to preserve the best form of root, to insure necessary richness, to forbid too strong doses of nitrogenous matter in the form of animal manure, and to guard against the disturbing causes, whose dangers I have already pointed out—dangers which are

increased whenever manure composed of spent oil-cake, Flemish manure or animal matters are injudiciously used.

I now arrive at the most delicate part of the question, namely, what manure is best suited for beetroot? On this point there are two very different cases to be considered: first, where chemical manures only are employed to the exclusion of all others; and, secondly, where they are associated with farm manure.

In the first case I recommend the normal stimulating manure, No. 2, and the normal stimulating manure, No. 2A, the last possessing in the highest degree all the requisite qualities:—

Normal stimulating manure, No. 2.		Quantity	Price		
		lbs.	£	s.	d.
Calcic superphosphate . . .		352	0	15	4
Potassic nitrate . . .		176	1	18	4
Sodic nitrate . . .		396	2	8	7
Calcic sulphate . . .		220	0	1	7
		1,144	£5	3	10

The quantity of nitrogen contained in this manure, which is excellent, is 187 lbs.

We read in all industrial chemical treatises that certain salts detract from the quality of beetroot, and this is especially the case with the alkaline chlorides. You will understand that in seeking to establish a theory of vegetable production from a multitude of experiments instituted under the most varied conditions, in artificial soils formed of calcined sand, or in naturally poor soil, as I have done for fifteen years at Vincennes, one is forced at least for a time to admit opinions that are recognised by science as demonstrated facts.

The chlorides being reputed hurtful, I began by eliminating them from any formulæ of manures; this was a concession to prevailing ideas.

But the late earthquakes in Peru having destroyed the stock of nitrates, the price of this salt rose enormously; potassic nitrate especially rose in price, from 1*l.* 6*s.* to 1*l.* 12*s.* and even to 1*l.* 16*s.* per cwt. This almost prohibitory price led me to employ potassic chloride in manures.

I had been struck with the fact that Scheele and Berthollet found that alkaline chlorides mixed with calcic carbonate in a porous medium decomposed and passed into a state of carbonate. It was, indeed, by means of this reaction that Berthollet had explained the formation of natron in certain lakes in Lower Egypt. In obedience to these

ideas I then tried to use with the stimulating manure, No. 2, the formula of which I have just given, manures containing potassic chloride, and notably the following:—

Normal stimulating manure, No. 2A.¹

	Quantity lbs.	Per acre Price		
		£	s.	d.
Calcic superphosphate . . .	352	0	15	4
Potassic chloride at 80° . . .	176	0	12	10
Ammonic sulphate . . .	176	1	12	0
Sodic nitrate . . .	308	1	17	4
Calcic sulphate . . .	132	0	1	0
	1,144	£4	18	6

Like the first, this manure contains 187 lbs. of nitrogen per acre. But when beetroot is grown too often upon the same soil, the crops have become uncertain and the roots of bad quality; this manure is then insufficient. The deep layers of the soil have suffered a loss which must be repaired. In this case the quantity of manure must be increased 50 per cent. and divided into two portions, one for the sub-soil, which is buried by a special dressing, the other being reserved for the surface and spread out in the usual manner. For the deep layers:—

	Per acre lbs.
Calcic superphosphate . . .	176
Potassic chloride at 80° . . .	176
Ammonic chloride . . .	88
Sodic nitrate . . .	88
Calcic sulphate . . .	176

For the surface:—

	lbs.
Calcic superphosphate . . .	352
Potassic chloride at 80° . . .	176
Ammonic sulphate . . .	124
Sodic nitrate . . .	264
Calcic sulphate . . .	140

These two manures represent together an expense of from 6*l.* 8*s.* to 8*l.* per acre. But the following year, with 1 cwt. more of ammonic sulphate, we obtain a yield of from 33 to 44 bushels of wheat per acre. In first introducing potassic chloride into the manure for beetroot I was groping in the dark, but it was a happy inspiration that led me to

¹ See my work *On the New Formulæ of Chemical Manures*, 1871. Agricultural Library, 26 Rue Jacob, Paris.

this decision, for it is with manure of this kind that I have obtained beetroot richest in sugar.

In going more deeply into the question I was surprised to find that in proportion as the richness of the beetroot increases the salts diminish. In proportion as we improve the variety and as we perfect the manure the salts disappear; scarcely any, or only a very small quantity, remaining in the roots.

Whilst on this subject I will relate a circumstance which will, I think, prove interesting, and prove, moreover, the truth of the assertions I have made.

Last year M. Pagnoul, whose excellent remarks upon the unfavourable effects of animal manure when used alone I have already noticed, wrote to me as follows:—

“How far have you got with your researches on beetroot, and what results have you arrived at?” M. Pagnoul was led to put this question to me because the Society of Agriculture at Arras had asked me in 1868 to give a lecture on the subject of beetroot, on which occasion I gave the result of a very decisive experiment made in Belgium by M. Verlat-Carlier, on soils that refused to produce beetroot, but where I had succeeded in growing roots containing 13 per cent. of sugar, at the rate of 16 tons per acre. I then somewhat diffidently, in a less affirmative form than at present, pointed out the facts which I have just laid before you.

Instead of telling M. Pagnoul of my progress I sent him three baskets of beetroot, saying: “Examine for yourself and ascertain the quantities of salts and of sugar, judge the quality, then get beetroots from the most noted growers, analyse them and draw your own conclusions”. The result of this comparative study will be seen from the following table:—

Beetroot grown in the Locality.

No.				Weight of roots			Percentage of sugar
				lbs.	oz.		
1	.	.	.	8	12	.	7·3
2	.	.	.	3	5	.	9·2
3	.	.	.	2	12	.	8·0
4	.	.	.	2	10	.	8·8
5	.	.	.	2	10	.	6·0
6	.	.	.	1	12	.	6·6
7	.	.	.	1	10½	.	8·8

Average, 7·8 per cent. of sugar.

Beetroot from the Experimental Field at Vincennes.

SPECIMEN NO. 1.

No.	Weight of roots			Percentage of sugar
	1 lb.	3 oz.		
1	.	.	10 $\frac{3}{4}$	10.1
2	.	.	0	11.9
3	.	.	6 $\frac{1}{4}$	14.3
4	.	.	5 $\frac{1}{2}$	15.2
5	.	.	3 $\frac{1}{2}$	15.0

Average, 13·3 per cent. of sugar.

SPECIMEN NO. 2.

No.	1	.	.	Weight of roots lbs. oz.	Percentage of sugar
"	2	.	.	3 12	11.4
"	3	.	.	2 13	16.4
"	4	.	.	2 8	16.3
"	5	.	.	1 12	15.3
"	5	.	.	0 11	17.9

Average, 15·4 per cent. of sugar.

SPECIMEN NO. 3.

No.				Weight of roots		Percentage of sugar
	1	.	.	lbs.	oz.	
	1	.	.	4	0	12.3
"	2	.	.	2	8	13.8
"	3	.	.	1	8	15.4
"	4	.	.	1	5½	17.2

Average, 14·6 per cent. of sugar.

I may add that these analyses were made in the month of January, that is to say at a time when beetroot begins to lose its richness.

I have said that, as the quality of the beetroot improves, the proportion of soluble salts is diminished.

The following examples go to prove this:—

Beetroot.

No.	1	2	3	4	5	6	7	Salts in 100 parts of sugar
	.	.	.	.	.	.	.	11·6
"	2	.	.	.	.	.	.	9·6
"	3	.	.	.	.	.	.	11·5
"	4	.	.	.	.	.	.	10·8
"	5	.	.	.	.	.	.	21·8
"	6	.	.	.	.	.	.	19·6
"	7	.	.	.	.	.	.	10·8

Average, 13·6 of salts in 100 parts of sugar.

Beetroot in Experimental Field.

SPECIMEN NO. 3.

						Salts in 100 parts of sugar
No. 1	.	.	.	.	.	4.3
„ 2	.	.	.	.	.	3.3
„ 3	.	.	.	.	.	1.3
„ 4	.	.	.	.	.	1.4

Average, 2.6 of salts.

The average results, both as regards sugar and salts, are summed up as follows :—

		Percentage of sugar in roots			Salts in 100 parts of sugar	
Beetroot	{ No. 1	.	.	.	13.3	3.9
from	{ „ 2	.	.	.	15.4	3.6
Vincennes	{ „ 3	.	.	.	14.6	2.6
Beetroot of ordinary quality		.	.	.	7.8	13.6

My experiments this year at Vincennes have enabled me to carry still further the discussion as to whether the richness in sugar of beetroot is dependent on its poverty in salts. We are almost able to judge the saccharine richness of beetroot by the quantity of ash left after combustion.

Here are some examples classed according to richness in sugar :—

Percentage of sugar in fresh beetroot					Percentage of ash in dried beetroot	
20	.	.	.	.	2.8	
15	.	.	.	.	3.6	
10	.	.	.	.	5.1	
5	.	.	.	.	10.0	

We find by analysis, moreover, that the richer the beetroot is in sugar the less abundant are the potassium and sodium salts. The following table shows that the proportion of lime is increased and that of potash diminished :—

Percentage of sugar in fresh beetroot					In 100 parts of ash	
					Potash	Lime
20	.	.	.	.	—	—
15	.	.	.	.	21	8
10	.	.	.	.	31	4
5	.	.	.	.	38	4

The beetroot poorest in salts and chlorides has been grown with potassic chloride manure. I confess that this fact for a long time puzzled me. It was to this that I referred when I said that notwithstanding important practical results the theory presented gaps that it was impossible for me to fill up.

New light has been thrown on the subject, and it is to MM. Violette and Pagnoul we are indebted for it: the alkaline chlorides are not localised in the tissues of the roots. By a sort of natural dialysis they concentrate in the collar of the root and in the blades of the leaves. This then explains the exceptional poverty in alkaline salts of the beetroot obtained with manure containing potassic chloride. Whilst I was ignorant of the fact pointed out by M. Violette I spoke of these manures with a certain reserve. From the good results they had given me I was bound to recommend a trial, although it was impossible to explain the poverty of the roots in alkaline salts.

Without again reverting to the preparation of the soil, I ought to point out an excellent method of cultivation which is beginning to be followed at Brie, where M. Belin, one of the best farmers in the Department of the Seine and Marne, has been making the trial according to my instructions.

The first year the soil was well ploughed, and 16 tons of manure per acre were spread at the bottom of the furrows; the earth was further left in this condition with the furrows open during the winter, and in the spring it was harrowed, without being ploughed again, and finally, 528 lbs. per acre of normal stimulating manure No. 2A, was spread upon the surface of the soil. The second year beetroot was still cultivated. But with a full quantity of the stimulating manure, No. 2A, the precaution was always taken of leaving the earth in open furrows during the whole of the winter. The third year wheat was sown. The two succeeding growths of beetroot did the soil an immense amount of good. What remained of the nitrogenous matter from the two preceding manurings was amply sufficient for the needs of the wheat; and the state of extreme division in which it existed in the soil preventing too hasty action, it gave admirable regularity to the progress of the wheat, and the result was an excessive crop of grain.

This year, at M. Belin's farm, the wheat was, soon after the first crop of beetroot, supplemented by ammoniac sulphate, and the product was 34 bushels per acre; the same variety of wheat, sown after the second crop of beetroot and without the aid of ammoniac sulphate, produced 46 bushels per acre.

In conclusion, I will recapitulate the propositions I have presented to you:—

1. Avoid the use of animal manure, or at least use it in moderate quantities only, and then associate it with chemical manure.

2. With the normal chemical manure beetroot is richer in sugar than with animal manure. It is necessary in the formulæ of chemical manures that the proportion of nitrogen should be from 70 lbs. to 88 lbs. per acre.

3. If you wish to associate chemical manure with animal manure do not use more than 16 tons per acre of the latter ; it should be laid on in the autumn and buried in the deep layers of the soil ; leave the earth in furrows all through the winter, and in the spring harrow it and give it a dressing of 528 lbs. of one of the two chemical manures that I have indicated.

4. Pay particular attention to the production of the seed. Reject as seed-plants all those that are badly shaped, too large, and, as a rule, all those that yield less than 14 per cent. of sugar. Renew the seed every second year.

The observance of these rules will procure yields of from 18 to 20 tons of roots per acre, and beetroot yielding on an average from 12 to 15 per cent. of sugar.

Now that we are approaching the end of our studies, let us for a moment look back at the road we have traversed. It was customary in the past to assert that the only true manures were those which contained all that the plants themselves contained, of which farm manure was the most perfect type. We have replied that to ensure the fertility of the soil it is only necessary to give it calcic phosphate, potash, lime and nitrogenous matter, four substances of which the united weight is equal at most to only a tenth part of the weight of the crops.

In opposition to the assertion that farm manure is equally suitable to all plants, we have been able to prove that to obtain good crops economically it is necessary to vary the nature and the composition of the manures.

To those who see the perfection of art in cultivation by means of cattle, we reply by demanding the accounts, and from these accounts we prove that the system does not yield profits proportionate to the actual value of the money, and does not supply to the market crops commensurate with the requirements of the population.

To those who call live stock a necessary evil, we reply that live stock may become a source of profit upon a farm ; but this can only be done by manuring the grass with chemical manure. And the same laws that render cultivation remunerative must be applied to the feeding of the cattle ; the animals must be fattened by an abundant and judiciously proportioned system of feeding.

To crown this collection of facts and ideas, we have the

practical results, which show the advantage of an alliance between manufactures and agriculture with the view of obtaining more manure. Practice, then, without any other guide than empirical observation of facts, has been able to conceive a system of which science could only give the theory and explain the advantages.

LECTURE XVI.

THE FIXATION OF THE NITROGEN OF THE AIR FOR MANURIAL PURPOSES.

THE most important crop now grown upon the earth is wheat, the consumption of which is steadily increasing. Both the average individual consumption per head and the number of bread-eaters are growing, the latter with great rapidity, and it was pointed out by Sir William Crookes in the Presidential Address before the British Association at Bristol in 1898 that the world's wheat supply must in the near future be augmented by some means then practically unknown, if universal starvation is to be warded off. An increase in the total area upon which wheat can be grown is manifestly impossible, since its cultivation is limited by definite meteorological and geological conditions. Hence when all the land available for wheat growing has been planted a bread famine will be in sight, unless the average yield of grain per acre has meanwhile been increased. Sir William Crookes showed that if all the possible wheat-growing land were taken up the total amount grown would only suffice to supply the increase of bread-eaters until the year 1931, supposing the average yield per acre to remain stationary. The general adoption of another grain as the staple food substance would in all probability give a set-back to the progress of the human race, for wheat has proved the sole cereal food fitted for those nations whose mental and physical development is at its highest pitch.

The chief manurial requisite for the wheat crop is nitrogen, applied either as an ammonium salt or as a nitrate; the plant is unable to draw upon the stores of molecular nitrogen occurring in the free state in the air, and can only assimilate that which is supplied to it in the chemically fixed state. Ammonium sulphate, a by-product of the gas works, is an excellent fertiliser, but is produced in comparatively small quantity, and for various reasons there seems to be no likelihood of a great in-

crease in the supply put upon the market. The chief nitrogenous manure now used for the wheat plant is Chili saltpetre, the beds of which will be exhausted in about fifteen years, if it is exported in sufficient quantity to provide adequate manuring for the increasing wheat fields of the world. That is to say, by the year 1923 the manuring of wheat will have to be performed by some artificial fertiliser which can be prepared cheaply in bulk, and which contains considerable quantities of fixed nitrogen. An illimitable source of the most important constituent of this manure, and one which, moreover, costs nothing, is the air and the problem of the fixation of atmospheric nitrogen has become one of the utmost importance. During the last ten years, since the argument stated shortly above was first put before the public, strenuous efforts have been made by some of the world's greatest reasoners and experimenters to determine at any rate in what direction we are to look for the solution.

Three different methods of utilising atmospheric nitrogen suggest themselves. Since some plants are capable of directly assimilating the nitrogen of the air, it was hoped that the study of the conditions under which the assimilation takes place might lead to results of importance. Secondly, in the Presidential Address Sir William Crookes pointed out a possible process for effecting the fixation. In 1892 he had demonstrated that nitrogen under certain circumstances is a combustible gas, burning with a powerful flame when a strong induction current passes through air; and he suggested that if the water-power of great waterfalls such as Niagara could be used to generate electricity, the cost of the combined nitrogen could be made so low as to enable it to compete with Chili nitrate. Finally, the decomposition of calcium carbide by the nitrogen of the air gives a nitrogenous product which can be used directly as a fertiliser.

The first and theoretically simplest method has only very recently been investigated, but the work has led already to some useful results. It has long been known that plants belonging to the family of Leguminosæ, such as clover, are capable of directly abstracting nitrogen from the air and can thus cause an accumulation of nitrogen in the soil, in a form in which it can readily be assimilated by a succeeding crop. If, then, a crop of clover or other leguminous plant were grown on a plot of land say once in three years, the amount of available nitrogen would increase, and thus the fertility of the soil would be raised. This method of fixing nitrogen would, however, in the end defeat its own purpose, for the increased fertility could be attained only by growing

wheat two years out of three, which would entail the sacrifice of a certain proportion of the world's wheat crop every year. However, the steady researches of botanists on the peculiar power possessed by leguminous plants have at last been crowned by a measure of success, and valuable practical results have been obtained. As long ago as 1886 the German chemists Hellriegel and Wilfarth, by a thorough investigation of the leguminous plants, showed that these plants obtained their nitrogen directly from the air, through the agency of certain excrescences or nodules found on the roots. These nodules had already been observed by Malpighi 200 years before, and had been regarded as galls, tumours, or imperfect buds by him and by later workers. Hellriegel and Wilfarth proved that there is a close connection between the absorption of nitrogen and these nodules, and they also noticed that the vigour of the plant increases with the number of nodules. Finally, they found that the nodules are inhabited by bacteria. The examination of the internal structure of the nodules by Hellriegel and Wilfarth, and also by Ward and others, led to the isolation of the bacterium which was named *Bacterium radicicola* by Beijerinck.

It was found that the fixation of nitrogen by this bacterium is due to a symbiotic or joint action of the bacterium with the plant. The bacterium requires for its growth and development carbohydrates and inorganic matter, which it obtains from the plant upon which it grows, while in its turn it supplies the plant with the essential nitrogen by fixing it directly from the air. Thus the plant forms the carbohydrates which the bacterium requires, and the bacterium forms the nitrogen compounds for the assimilation of the plant. The experimental stage of the investigation might now have been expected to make way for its development upon a commercial scale, and the application of the knowledge gained seemed comparatively easy. For if the bacterium could be grown and soil were inoculated with the culture, a vigorous clover crop could be ensured, and the fixation of nitrogen promoted, to the benefit of the succeeding cereal crop.

Professor Nobbe of Germany took up the matter, and first of all showed that the fixation was not the work of a single bacterium, but of a class of organisms, each leguminous plant having its own characteristic bacterium, and the bacterium of one plant appeared to be unable to exist upon another plant of the same order. He then proceeded to grow cultures in gelatine for the inoculation of the roots of leguminous plants, and the cultures were placed upon the market under the name "Nitrogin". No success, however, attended this venture, and

in the majority of cases in which they were tried the cultures proved a failure. An improved method of preparing the cultures was then suggested, but it gave no better results, and the manufacture of the preparation was abandoned. However, within a comparatively short space of time the explanation of the failure had been discovered by Moore of the United States Department of Agriculture at Washington. Moore found that when the bacteria are provided with nitrogenous matter in the form of gelatine the elaboration of compounds from the nitrogen of the air stops, the bacteria obtaining all that they require in the more easily assimilated form. When the supply of nitrogen in the gelatine has given out the bacteria have lost the power of evolving nitrogen compounds from the nitrogen of the air, or at any rate this power has decreased to such an extent that the organism, deprived of the nitrogenous gelatine, succumbs to starvation. Moore suggested that the remedy would be the withholding of nitrogenous material from the cultures, and within two years American cultures for inoculation were being distributed amongst agriculturists for trial. In this case the culture was dried on cotton wool, and was given gratis to all who applied for it, with full directions for its use. Seventy-four per cent. of the results obtained were reported to be satisfactory, the crops having benefited to a marked degree by the use of the culture. In 1905 the British Board of Agriculture imported some of the American preparations for trial at thirteen different agricultural colleges and stations. The results obtained were both positive and negative, and the report issued by the Board was on the whole unfavourable to the new preparations, and described the subject of plant inoculation as having not yet passed the experimental stage. American investigators, however, soon found that the cause of this failure was that the bacteria die in from six to eight weeks from the time they are first dried, so that British agriculturists, who did not follow the exact directions, were frequently using dead or dying material. Professor Bottomley of King's College, London, was meanwhile conducting a research, the result of which was the discovery of an improvement of the process by which the bacteria could be given a longer life. They were dried and issued in the form of a powder in which they retained their activity for some months.

In order that his cultures might be given a fair trial Professor Bottomley undertook the distribution of them to all agriculturists who applied for them, and the results obtained were highly satisfactory in 80 per cent. of the cases reported. Not only were the plants invigorated and the crop increased,

but also the maturing of the crop was greatly hastened ; under suitable conditions the crop was found to contain more nitrogen, and thus was of higher value as a feeding stuff, and its growth improved the soil for subsequent crops.

Professor Bottomley's experiments showed that under some circumstances the inoculation of the soil with the culture would not benefit it to any marked extent, and he undertook an exhaustive research to investigate these circumstances. The results of his work may be stated briefly as follows : When the soil is already rich in nitrogen the development of the tubercle is arrested ; hence inoculation is most beneficial to poor soils which contain but little organic matter and have not recently been under a leguminous crop. When the soil is acid, and requires lime, this must be added before inoculation is performed. And since inoculation provides only for the nitrogen necessary for plants, the application of phosphates and potash must obviously not be neglected.

Some of the results obtained by practical farmers who tested Professor Bottomley's cultures are tabulated below.

In many cases the yield was simply described as "better" or "very much better," but in the following instances estimated figures were given, or results actually obtained were stated :—

I. INCREASED YIELD.

Crop.	Locality.	Percentage Increase of Yield.
Peas	Marazion	20
Peas	Weymouth	20
Broad Beans	Staunton	42
Peas	Staunton	141
Clover	Faversham	25
Beans	Canterbury	27
Beans	Grappenhall	30
Peas	Desford	20
Peas	Whilton	30-40
Runner Beans	Harrow	45-50
Peas	Norwich	50
Peas	Marsham	200
Clover	Tamworth	15
Tares	Tamworth	10
Sweet Peas	Sutton, Surrey	33½
Peas	Redhill	35-40
Runner Beans	Sheffield	43
Peas	Kelso	50
Peas	Wormit, Fife	100
Clover	Forres	100
Beans	Ruthenglen	122½

II. EARLY MATURING OF CROP.

Crop.	Locality.	Ripening Accelerated.
Peas	Marazion	14 days.
Broad Beans	Staunton	10 days.
Runner Beans	Ramee, Guernsey	6 weeks after sowing.
Peas	S. Onen	7 days.
Peas	Oswestry	4 weeks.
Beans	Knapp Hill	3 weeks.
Peas	Sheffield	14 days.

III. INCREASED FERTILITY OF SOIL.

Statistics relating to the increased fertility of the soil resulting from inoculation are difficult to obtain, although there is abundant evidence to prove that a vigorous crop of a leguminous plant adds a considerable amount of organic nitrogen. The following table shows the results of some experiments carried out in America :—

Crop.	Original Yield per Acre.	Yield per Acre after Inoculated Crop.	Gain per cent.
Potatoes	67·8 bushels	102·2 bushels, after crimson clover.	50
Oats	8·4 bushels	33·6 bushels, after velvet beans.	300
Rye	4·5 bushels	23·5 bushels, after peas.	400
Wheat	18·6 bushels	26·9 bushels, after melilotus.	46

IV. INCREASE OF FEEDING VALUE OF CROP.

An interesting series of comparative tests carried out at King's College showed conclusively that the amount of nitrogen in an inoculated crop is considerably in excess of that in a non-inoculated crop. Two sets of tares were grown in sterilised soil, to which the necessary amount of potash and phosphate had been added. To one lot sodium nitrate was added in the proportion of 2 cwts. to an acre, while the other lot was inoculated. At the end of the season the nitrogen in the two crops was determined, the results being :—

Nitrogen in tares with sodium nitrate	= 1·92 per cent.
Nitrogen in inoculated tares	= 3·07 per cent.

Similar experiments carried out with lucern at the College Experiment Station, Kilmarnock, gave the following results :—

Section A—no nitrogenous manure	3.41 per cent. nitrogen
Section B—2 cwts. nitrate of soda per acre	3.75 per cent. nitrogen
Section C—inoculated	4.04 per cent. nitrogen

Thus in this case the increase of feeding value was appreciable, though smaller than before. The plants in the two first plots had some tubercles on their roots. It is, moreover, to be noted that when the total weights of the crops are compared the third is 30 per cent. more than the second. Thus:—

Section A	gave	7 tons	0 cwts.	3 qrs.	per acre.
Section B	gave	9 tons	8 cwts.	2 qrs.	per acre.
Section C	gave	12 tons	5 cwts.	0 qrs.	per acre.

While the first cultures were being used for leguminous plants with the results stated above, other plants were being investigated at King's College, London, in order to find out whether they possessed the power of fixing atmospheric nitrogen. It had for some time been known that four plants—*Eleagnus*, *Alder*, *Podocarpus* and *Cycas*—had tubercles on their roots and by means of them could fix free nitrogen. The bacteria in the roots of these plants were found on the exterior instead of in the centre as in the case of the leguminous plants. It then occurred to Professor Bottomley that it might be possible to induce the bacillus of one plant to attach itself to another, which it would benefit by symbiosis. For this purpose he isolated the bacteria from the nodules of a leguminous plant, and bred them for ten generations upon extract of tomato root. The result was that they acquired the power of living in symbiosis with the tomato plant, which developed nodules, and showed a marked increase in growth and vigour. Similar experiments with cabbages, strawberries and roses led to the same results, while oats also have been experimented with and have given equally satisfactory returns. Further investigation will no doubt show that other plants can be benefited in the same way.

Professor Bottomley's culture, which is sold under the name "*Nitro-Bacterine*," is exceedingly simple in its application. It consists of three preparations in different packages. The first, containing suitable feeding salts, is dissolved in 1 gallon of pure rain water (which has previously been boiled and allowed to cool). The second package, containing the dried bacteria, is then stirred into the solution, and the tub or vessel is covered to exclude dust and kept in a warm place for twenty-four hours. The temperature must not be allowed to exceed 75-80° F. Finally, the third package is stirred in, and the mixture is allowed to stand until a cloudiness appears,

which will usually be within from twenty-four to thirty-six hours if a suitable temperature has been maintained. If the temperature is allowed to drop too low the growth of the bacteria may not be sufficient to cause the cloudiness in this period, and a longer time (not exceeding one or two days) must be allowed. It is essential that the solution should be cloudy before it is used. It may be applied in three different ways:—

- (1) To inoculate the seed.
- (2) To inoculate the soil.
- (3) To inoculate the crops.

In the first case the seed is either sprinkled with the solution or dipped in it, but not soaked. It is then thoroughly dried, not in direct sunshine, and planted in the usual way. It is not necessary to plant the seed immediately, and the dried inoculated seed may be kept for weeks even, without deleterious effect. The culture solution, on the other hand, *must* always be freshly made.

To inoculate the soil the cloudy culture solution is prepared as before, and diluted with its own volume of water. Then dry soil is thoroughly mixed with the solution, and the moist mass is further mixed with four or five times the quantity of dry soil, which is spread over the ground and treated in the same way as an ordinary fertiliser.

For growing crops one part of the culture solution is diluted with fifty parts of water, and the crops are watered in the usual way.

In many cases it is found advantageous to inoculate the seeds and also to water the young plant with the dilute culture solution. When the roots of plants, *e.g.*, tares grown from inoculated seed, are examined it is found that the tubercles form only on the tap-root; if, however, the young plant from inoculated seed is watered as well, the rootlets are far more numerous and tubercles are found on all of them. The growth of the roots of plants from non-inoculated seed is feeble, and tubercles are absent altogether. Comparative experiments on the effects of inoculating the seed only and inoculating both soil and seed, carried out with peas, showed that the inoculated seed gave a 20 per cent. better crop than seed not so treated, while inoculating both soil and seed gave a 30 per cent. better crop than treating the seed only.

The cost of inoculation is comparatively trifling, amounting to only a few pence per acre. One gallon of the culture will inoculate enough seed for twelve to fifteen acres of land, and average soil when inoculated at a cost of 3s. per acre gives a far higher yield of crop per acre than when treated with

nitrate of soda at 25s. per acre. Moreover, soils which are now incapable of bearing any crop, such as the bog land of Co. Mayo, have grown a strong crop of rich herbage, pasture land has been greatly improved, and in one case when inoculated clover and oats were sown together a good crop of oats resulted where no crop had ever before been obtained. Parts of the same field which were left non-inoculated produced only a very poor crop.

II. *Electrical Methods of Fixing Nitrogen.*—In the year 1781 Cavendish noticed that when hydrogen burns in air the product is not pure water, but water containing nitric acid, and five years later he proved that an electric spark discharge is capable of inducing the combination of gaseous oxygen and nitrogen. Priestley had also observed the same phenomenon, but neither investigator had the least conception of the possible practical importance of his discovery. In later years the combustion of nitrogen in oxygen was studied by, among others, Spottiswoode and Dewar, Crookes, Lord Rayleigh, Dougall and Howles, Von Lepel, Nernst and Scheuer, and although the results obtained were in some cases contradictory, and not very encouraging from a commercial point of view, it was pointed out by Sir William Crookes, in 1898, that the problem of the production of electricity at a sufficiently cheap rate to make the fixation of nitrogen electrically a financial success might be solved by the utilisation of water power. His suggestion has been adopted, and all the electrical processes now working depend upon water power for the generation of the necessary electrical energy.

Preliminary experiments upon the conditions best suited for the oxidation of nitrogen in the electric arc showed that the process is purely thermic, and that the difficulty of getting a high yield of nitric oxide in the gases through which the arc has passed is due to the fact that the formation of nitric oxide is an endothermic reaction, and requires the constant addition of energy. The researches of Nernst on this subject are particularly interesting. He investigated the formation of nitric oxide at high temperatures by passing known volumes of air through an iridium furnace at a known temperature, and determining the resulting nitric oxide in the rapidly cooled exit gases. He thus found that the velocity of the reaction is a function of the temperature; at 1000° the velocity is very small, while at 2100° it has enormously increased, the time taken to reach the half-equilibrium point being only 5.06 seconds. Nernst's work showed that a very high temperature is the first essential for a high concentration of nitric oxide in the resulting gases. When, however, the arc flame is studied

to determine how it may best be employed to produce the high temperature necessary to bring about combination, it is found that there are very serious difficulties to be overcome before it can be applied satisfactorily. Like the flame of coal gas in air it consists of three zones, which, however, differ fundamentally from the gas flame zones. The inner zone in which the temperature is highest, *i.e.*, about 4200° , is the one in which oxidation occurs; in the middle zone the temperature has fallen to about 1400° , and the nitric oxide undergoes partial dissociation, while in the third, outer, zone the temperature is in the neighbourhood of 900° and a further dissociation of the nitric oxide formed in the innermost zone takes place. The experimental work of Muthmann and Hofer and of Brode has shown that the greatest concentration of nitric oxide can be reached by withdrawing it as quickly as possible from the influence of the second and third zones in which dissociation takes place, and they have proved that one of the essential conditions of the economical production of nitric oxide is the lowering of the temperature of the reacting gases with the utmost rapidity. This condition can be fulfilled in one of two ways—firstly, the air can be passed with enormous velocity through the arc, or secondly, the arc can be moved very rapidly through the air. The processes which seem most likely to be destined to succeed commercially are those in which the latter device is adopted.

The first attempt to produce nitric acid from the air upon a large scale was the process of Messrs. Bradley and Lovejoy, who, adopting the suggestion that water power would be the cheapest source of the necessary electrical energy, endeavoured to take advantage of the energy generated by the water power of Niagara for the purpose. A company was formed—the Atmospheric Products Company—and a small trial plant was established to test the practicability of the process. A high tension (10,000 volts) direct current was employed, and as it is a matter of difficulty to induce discharges at high voltages to pass steadily, the inventors constructed their apparatus in the form of rotating drums fitted with projecting electrodes. When these approached one another they produced spark discharges which were immediately interrupted. However, it was found that the cost of working the process was such that the synthetic product could not compete in price with Chili saltpetre, and the experiment was abandoned in the summer of 1904. The central idea of distributing the electrical energy among a great number of small arcs of short duration was valuable, for it enabled the energy consumed in the arcs to be kept fairly steady, but the technical difficulties

FIG. 1.

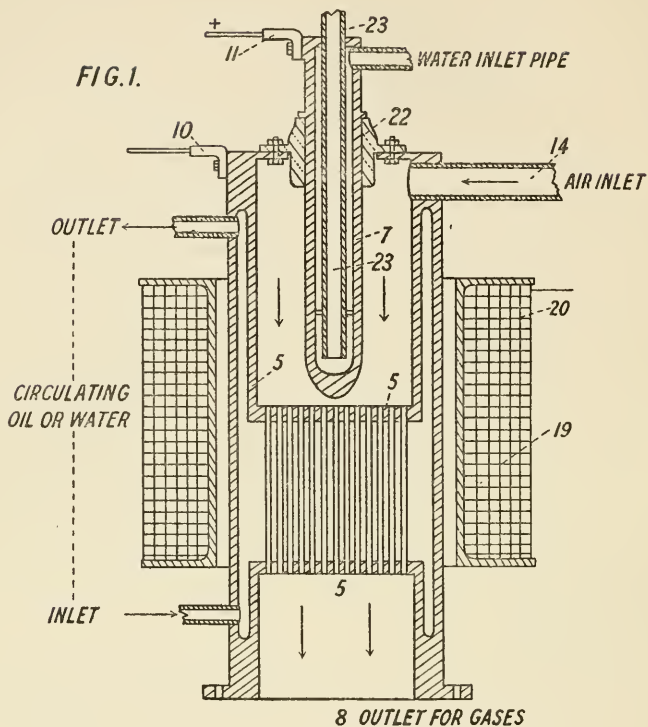
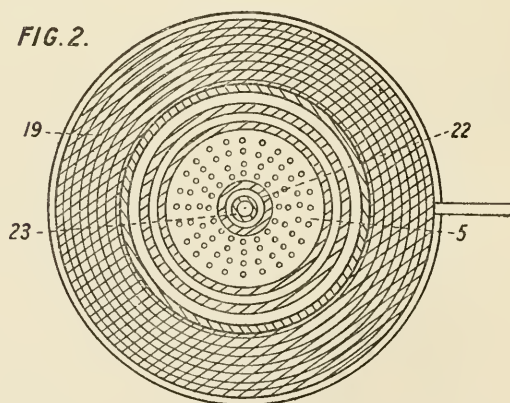


FIG. 2.



of carrying out this idea upon satisfactory financial terms were soon found to be practically insuperable.

The experiments which have been carried out by Kowalski and Moscicki at Fribourg appear to be much more promising, and the tests to which their process has been subjected have in many respects given most satisfactory results.

The form of their latest furnace is shown in Figs. 1 and 2, and it consists of a jacketed cylinder, 5, which contains a tubular cooling apparatus arranged in such a manner that water or oil may be circulated in the jacket and round the tubes of the cooling apparatus. An electric current at about 2,000 volts passes from the rounded end of the electrode, 7, to the flat upper surface of the cooling apparatus, 5, in the field of a strong magnet coil, 19, which results in the flame revolving rapidly and spreading over the upper surface of 5 in such a way that this surface appears to the eye to be covered with a continuous sheet of flame. The velocity of the flame *ceteris paribus* is dependent upon the intensity of the current passing through the magnet coil 19. Thus the flame may be forced to return to its starting-point after any desired period.

The superiority of this furnace is that, although the air entering through the pipe, 14, as it reaches the revolving flame is exposed to the very high temperature of at least 3000° C., which is necessary for the economical formation of nitric oxide gas, this gas is cooled in a minute fraction of a second to a temperature of 700° C., which is required for preventing the subsequent decomposition of the gas formed in the electric flame, by passing it through the cooling apparatus. In other furnaces this cooling is effected by admitting a large surplus amount of air to produce the same result, and such excess reduces the percentage of nitric oxide in the resulting volume of air and gas. Thus, the air and gas which escape from the furnace owing to great dilution make the subsequent absorption process for converting nitric oxide into nitric acid difficult, if not impossible.

The current employed at the experimental plant at Fribourg was a high voltage (8,000 volts) alternating current with 50 periods in a second. Since only 2,000 volts would be required for the process this current would be sufficient to supply four furnaces connected in series. A large choking coil enabled the number of amperes in the furnace to be regulated between fourteen and forty. The ignition was provided for by a battery of Moscicki's high tension condensers, in which the 8,000 volt current, transformed to 50,000 volts, was changed into a high frequency current. The gases emerging from the furnace were origin-

ally received in two absorption towers, but as no measurable quantity of nitric oxide was ever detected in the second, one proved to be sufficient. In the trials of the process, conducted in June, 1907, the electrical energy absorbed, during a specified time of working, the total amount of nitric oxide in the furnace, and the percentage of nitric oxide in the gases issuing from the furnace was determined. The gases withdrawn for analysis were passed through an absorption tower filled with glass balls and covered with a deep layer of glass beads, the whole being kept well moistened with potash solution. A measured excess of standard potash was used, and the volume of the gases leaving the absorption tower was measured. The washings from the tower, mixing bottle and connecting tubes were made up to a certain volume, and an aliquot part was titrated with standard acid. The results obtained were checked by determining the amount of nitrogen in the solution by Crum's method (liberation of nitric oxide by shaking with mercury and strong sulphuric acid), and it was found that the two methods gave absolutely concordant results. Two trials were made under conditions of limited power supply which did not allow of the working of the furnace to its full capacity. The highest yield of absolute nitric acid was found to be about 430 kilogrammes per kilowatt year, and the percentage of nitric oxide in the exit gases was 1.92. The direct production of nitric acid from the furnace gases was specially investigated, and as long a run as possible was made in order to find out what strength of acid could be obtained. The length of the run was limited by the time the current could be supplied continuously, but the percentage of nitric acid in the aqueous acid steadily increased with the duration of the trial. At the end of the run, six hours from the start, the percentage by weight of nitric acid present was 17.6. There was no reason for supposing that this percentage could not have been increased by a longer run, and the acid obtained was free from notable quantities of the lower oxides. The direct production of nitric acid is of considerable scientific and commercial interest, and although the yield of nitrate per kilowatt year in this process, with the furnaces working under their actual capacity, falls below that obtained by other methods, the percentage of nitric oxide present may be found to be commercially of greater importance than the yield per kilowatt year, the inventors' efforts having been specially directed towards obtaining the most economical relationship between the yield of nitric oxide and the percentage contained in the issuing gases.

In 1903 K. Birkeland, the Professor of Physics at the

University of Christiania, and the Norwegian engineer Eyde, took out the patents of a new form of furnace, by means of which calcium nitrate can be prepared electrically from the air. In the course of his investigations Professor Birkeland had observed that when an arc formed by an alternating current of fairly high potential is situated in a magnetic field at right angles to the magnetic lines of force, a disc of sparks is produced, the arc being spread out into a series of flames, travelling in two directions. This phenomenon, which had previously been observed by Plücker in 1861, gives the observer the impression that he is looking at a steadily blazing sun, and the disc may be represented diagrammatically by the following figure, in which E and E' are alternately positive and negative. The appearance with a direct current is different, the arc taking a semicircular form. Plücker had also observed that when this disc of flame is produced in air brown oxides of nitrogen are formed. The disc of flame is apparently produced by a series of discharges, the noise of which can be heard while the flame is burning; these discharges are pulled aside by the strong magnetic force into curves, which are approximately semicircles like the ripples on a pond, gradually enlarging from a quarter of an inch to as much as 3 feet. With an alternating current all the arcs with a positive direction run one way, while all the negative arcs run the opposite way, and the flame extends farther along the positive than along the negative electrode. The arc is formed most satisfactorily when the potential is from 3,000 to 4,000 volts and the temperature is probably higher than that of the carbon arc. Professor Birkeland has made a special study of the nature of the arcs, which he finds assume the form of very fine threads of thickness about $\frac{1}{10}$ mm. when the disc flame has a diameter of about 6 cm.

The furnace designed by Birkeland and Eyde to utilise this method of preparing oxides of nitrogen from the air is constructed of firebrick contained in a metal casing. The arc chamber is shown at 2 in the accompanying diagram, the electrodes at 7, the magnets at 12, and the air inlet and outlet at 15 and 16. The fire-chamber is narrow in the direction of the lines of force, from 5 to 15 cm. wide, and the air is driven by a Roots' blower into the central chamber through holes in the fireclay walls. The horizontal electrodes are of copper, and are hollow, to enable them to be cooled by a steady current of water to prevent fusion. The magnets are excited by means of a direct current, and they consume 10 per cent. of the electrical energy used in the arc. The copper electrodes have to be renewed at intervals of a few weeks, running for

about 300 hours, and they absorb about 7.5 per cent. of the electrical energy of the arc.

After the first experiments, performed at Christiania, had shown that the method gave every indication of being a practical success, a research station was built at Ankerlokken, near Christiania, and a large plant of 120 kilowatts was constructed. In September, 1904, this station was abandoned, and the work was transferred to a larger experimental factory at Vasmoen, 20 miles from Arendal, where electric power up to 500 kilowatts could be obtained from a waterfall. This factory was established solely for the purpose of thoroughly investigating the new process, and it is still employed as a research station, where modifications and improvements of the original process are continually being tested. The inventors have here several furnaces of different sizes and patterns, together with all the electrical and chemical apparatus necessary for making every kind of measurement.

The commercial possibilities of the new process were now fully recognised, and the first industrial factory was erected at Notodden on the Hittersdal Lake. This lake is connected by means of canals and waterways with the Skein Fjord and thence with the open sea. Close to Notodden the river Tinnelf forms the Tinnfos Waterfall, where the river-bed drops some 40 feet, giving about 20,000 h.-p. A few miles up the river another waterfall, the Svaelffos, provides 29,000 h.-p., of which the available 26,500 h.-p. is to be transmitted to Notodden. The Nitrogen Company of Norway, which was formed for the purpose of developing Birkeland and Eyde's process commercially, have also acquired rights for the utilisation of three other waterfalls in South Norway, of which the Rjukanfos, giving a maximum of 30,000 h.-p., is the most important. At the Notodden saltpetre factory three furnaces are installed, each employing 500 kilowatts. With a working potential of 5,000 volts 3,500 volts are obtained on the electrodes. The inner firebrick surfaces of the furnaces have been estimated to require replacing two or three times a year, but probably this estimate is too high on an average and the firebrick will last longer than four or six months. The temperature of the inner wall does not rise above 700°, owing to the cooling effect of the current of air. The cost of a furnace to take 1,000 kilowatts is 1,000*l.* and the cost of erection is 1*l.*, so that the cost per kilowatt is roughly 1*l.*, but this sum would be considerably reduced if the furnaces were constructed on a larger scale, the estimated average being from 11*s.* to 12*s.* per kilowatt. The volume of air supplied to each furnace by the blowers amounts to 2,500 litres per minute. The hot gases which come

from the furnace (temperature 600° - 700°) contain 1 per cent. of nitric oxide. They first pass through a steam boiler, and are there reduced to a temperature of 200° ; then they enter a cooling apparatus, where they are further cooled to 50° . Finally they are conducted into two large oxidation chambers with acid-proof linings. Here the nitric oxide is oxidised to nitric peroxide, and the gases are then passed into the absorption towers, where the conversion into nitric acid takes place. These towers number ten in all, arranged in two series. In each series there are two granite towers and two of sandstone filled with quartz over which water trickles. The fifth tower of each series contains ordinary bricks, and in it the remaining nitrous gases are caught in milk of lime, calcium nitrate and nitrite being formed. The first tower yields 50 per cent. acid, the second 25 per cent., the third 15 per cent. and the fourth 5 per cent. By raising the liquids from the fourth, third and second towers in each case to the top of the preceding tower the concentration is raised to 50 per cent. The liquid is then removed to open granite tanks, where it is temporarily stored. The 50 per cent. acid is treated with limestone and the resulting liquid is concentrated until it contains 75-80 per cent. calcium nitrate, with 13.5 per cent. of nitrogen. It is then run into iron drums and is ready for the market. The Norwegian Nitrogen Company have at their disposal unlimited quantities of very pure limestone, and as caustic soda would have to be imported, it was decided to sell the product as nitrate of lime and not as nitrate of soda. By the addition of quicklime a basic nitrate is produced, which is quite anhydrous, whereas the normal nitrate crystallises with four molecules of water. If the yield is 500 kilogrammes of anhydrous nitric acid per kilowatt year, which is the lowest estimate, and the cost of electric power is assumed to be 0.1*d.* per unit, the cost of the calcium nitrate in power alone would be 4*l.* 10*s.* per ton, while the selling price is about 8*l.* In calculating the net profit, the cost of upkeep, interest on capital, labour, etc., must be taken into account, and as yet it is difficult to obtain reliable figures. In Norway the cost of power is not nearly so much as 0.1*d.* per unit. At a pulp factory situated near Notodden the cost per unit is about $\frac{1}{40}$ *d.*, and the owners sell part of their power to the saltpetre factory at 0.047*d.* per unit.

Of other processes which have been patented, and which appear to contain the germ of success, must be mentioned that recently described by the Badische Anilin und Soda Fabrik. This process possesses the merits of great simplicity of experimental arrangement, and it is not improbable that

further experiments may lead to its development upon a commercial scale. The flame, consisting of a single arc, is drawn out to a length of 1 metre or more in an iron tube. At one end of the tube an insulated electrode is situated, and a single electrode, connected with the tube, is inserted at the other end. When a current of a few thousand volts is passed, an arc is set up between the insulated electrode and the iron tube. Air is then blown into the tube with a whirling motion and the arc burns steadily. Several such tubes communicate with a common chamber, and it has also been found possible to establish several arcs in the same tube, each arc burning quietly between the electrodes. Each arc employs 100 kilowatts. This process is still in the experimental stage, and its possibilities are being investigated at the research station at Arendal.

Another process which is extremely simple in action is that patented by Naville and Guye in 1905. A disc-shaped electrode which is surrounded by refractory material rotates above and a short distance from a metal tube, through which air is blown. This tube forms the second electrode, and the rotation of the upper electrode causes the spreading of the arc. In this way a yield of 400 kilogrammes of nitric acid per kilowatt year has been obtained.

In Pauling's apparatus the electrodes are inclined to one another at an angle of about 45° in a vertical plane. A rotating wheel carries conductors, which set up an arc when they pass between the lower ends of the electrodes. This arc is forced up the electrodes by an air blast, and is finally extinguished when it reaches the upper ends of the electrodes, the process being repeated as each conductor on the rotating wheel passes under the lower ends of the electrodes.

Finally a patent which has been taken out in America merits the attention, for unless there are special difficulties to be overcome in constructing the apparatus on a large scale the process seems decidedly promising. This is Steinmetz' method, in which a long thin arc is produced between two electrodes which pass through the top and bottom respectively of a cylindrical glass or porcelain reaction chamber. The chamber is surrounded by the poles of a rotating electro-magnet. Thus the arc is bowed out sideways so that it takes the form of a segment of a circle, and at the same time the arc itself is given a rotating movement. When air is introduced into the chamber a large quantity of air is subjected to the action of the arc, while this action continues for such a short time that no local superheating can occur, and thus the decomposition of the oxide formed is altogether

avoided. So far no details as to the practical working of the process upon a large scale are to be found.

The maximum yield yet obtained by an electrical method of fixing nitrogen is 650 kilogrammes of nitric acid per kilowatt year, which is 79.3 per cent. of the theoretical yield, assuming the temperature of the flame to be 3200°C . Experiments which aimed at increasing the flame temperature by increasing the pressure of the gases surrounding the arc showed that although the exit gases contained only the same percentage of nitric oxide, the yield was increased three times per unit of energy consumed, the velocity of the air being greatly accelerated. The continuation of this work, which is being carried on by Muthmann and Hofer, may possibly lead to important developments.

The calcium nitrate put upon the market by the Norwegian Nitrogen Company is a new manurial agent; it has as yet either been consumed locally or else has been shipped to Hamburg. Experiments relating to its use have been made in Germany and elsewhere, and on the whole the results obtained have been concordant. The fertilising powers of nitrate of lime for equal amounts of nitrogen are approximately the same as those of nitrate of soda, except in special cases. On a sandy soil in which there is a deficiency of lime calcium nitrate has a more beneficial effect upon the crops than Chili saltpetre. Also it is preferable for use on clay rather than nitrate of soda, which gives rise to a stickiness, making the soil difficult to work. On the other hand it is unsuitable for application to chalk or other soils which themselves contain excess of lime. Among the crops which have been subjected to experiments to determine the comparative effects of manuring with nitrates of soda and of lime may be mentioned the following: Sugar cane, for which nitrate of lime is at least equal to nitrate of soda. Potatoes treated with nitrate of lime give a greater increase of starch than those treated with nitrate of soda. The Cruciferae, especially mustard, are particularly benefited by lime saltpetre. For oats in sandy soil and loams the two nitrates are equally valuable. Chili and lime saltpetres have approximately the same effect upon a crop of hay.

III. *Fixation of Nitrogen by the Manufacture of Calcium Cyanamide.*—The third method of fixing the nitrogen of the air depends upon the fact that the carbides of certain metals absorb nitrogen when they are raised to a high temperature and the pure gas is passed over them. This property is characteristic of the carbides of the metals barium, strontium and calcium, and it was first applied by Professor Frank and

Dr. Caro for the production of an artificial fertiliser. In the case of calcium carbide the products of the reaction are calcium cyanamide and carbon monoxide, the former being applied directly as a manure under the name "lime-nitrogen". When superheated steam acts upon calcium cyanamide the products are ammonia and calcium carbonate.

The experimental investigation of the process had shown that the chief factor in determining its commercial success was the possibility of obtaining cheap power and a cheap source of calcium carbide. The carbide is prepared by heating lime and coke to a high temperature in an electric resistance furnace. The first factory for the preparation of calcium cyanamide was put up at Piano d'Orta in Italy by the Società Italiana per la Fabbricazione di Prodotti Azotati. The carbide is obtained from neighbouring works, and pure nitrogen is separated from the air by fractional distillation of liquid air by Linde's process. The air is first dried and cooled under pressure to -194°C . By this means it is liquefied, and may then be separated by fractional distillation into oxygen and nitrogen. The former gas is compressed and sold in cylinders, while the nitrogen is passed into cylindrical furnaces which contain lump calcium carbide, and which are heated to the required temperature either by fuel or by electric means. When the absorption of nitrogen ceases the contents of the retort are cooled in absence of oxygen, and the cyanamide is then crushed to a fine powder and sold in sacks under the name "nitrolim" or "lime-nitrogen". A patent recently taken out by Dr. Frank deals with a method of making calcium cyanamide without employing calcium carbide. The furnace he has designed for this purpose is shown in the following diagrams. It consists of a brick chamber 6 metres long by 3 metres high and 3 metres wide. A pigeon-holed inner wall admits the nitrogen gas, and the furnace is charged with crushed lime and coke. A thin carbon rod serves as a conductor for the current until the mass is at a red heat, and acts as a conductor itself. At the Piano d'Orta factory there are six furnaces, each containing five retorts, in which 300 kilogrammes of calcium carbide can be converted into cyanamide in twenty-four hours. Thus the total output per annum of calcium cyanamide is at the rate of nearly 4,000 tons, and large extensions of the plant are contemplated.

Similar factories are being erected by a French company at Nôtre Dame de Briançon in Savoy, and at Odde upon the Hardanger Fjord in Norway under the direction of the North-Western Cyanamide Company of London, while a German

company proposes to work the process at Trostberg in South Bavaria, and at Bromberg in Posen cyanamide is already being made. The Odde works, which belong to the North-Western Cyanamide Company, are the largest which have yet been built. They are designed for a yearly output of 12,500 tons, and are so constructed that they can readily be extended to four times their present size. The American Cyanamide Company is making plans for the construction of a factory in North Alabama.

Various modifications of Frank and Caro's process have been proposed, one of the most important being that patented by Polzeniusz. It was found that the absorption of nitrogen by calcium carbide is much accelerated by the presence of any salt of calcium containing no oxygen, and especially by those with a low melting-point. Thus if a mixture is made of 23 per cent. of calcium chloride and 77 per cent. of carbide, it is found that the temperature of absorption is only about 700-750°. Moreover, the product, which has been made in bulk at Westeregeln by the Gesellschaft für Stickstoffdünger, and placed upon the market under the name "nitrogen-lime," is said to be free from the polymer of cyanamide, dicyanamide, which is supposed by some to have a deleterious effect upon the crops. The objection, however, to the use of nitrogen-lime is due to the fact that it is hygroscopic, owing to the known attraction of calcium chloride for water. Hence it has to be packed in air-tight casks and cannot be sold in sacks.

Another improvement upon Frank and Caro's process is that suggested by Carlson. In this modification calcium fluoride is added to the carbide, and acts in the same way as the chloride, lowering the temperature at which the absorption of gas begins. The fluoride, however, is not hygroscopic, and therefore the cyanamide thus obtained shows no tendency to absorb moisture.

The cost of the carbide method of fixing the nitrogen of the air is regulated by the cost of electric power to effect the heating, the cost of carbide and the cost of nitrogen. Where electric power can be obtained very cheaply, as, for instance, from water power, at the rate of 2*l.* per electrical-horse-power year, it is stated that the new fertiliser can be placed upon the market at a lower price than either nitrate of soda or ammonium sulphate, containing the same amount of nitrogen. The estimated power required to obtain 1 ton of nitrogen in the form of calcium cyanamide is two kilowatt years. Some important subsidiary products of the industry are sodium cyanide, liquid ammonia dicyandiamide (used in dyeing), salts

of guanidine and "surrogate". This last is a molten mixture obtained by melting nitrolim with a flux. It contains an amount of cyanide corresponding to 25 per cent. KCN, and can be used in the place of the latter for the extraction of gold.

The nitrogen-lime obtained from Piano d'Orta contains from 19-21 per cent. of nitrogen, and is thus about equivalent in this respect to an equal weight of ammonium sulphate. The nitrogen-lime from Westeregeln is stated to contain about 22 per cent. of nitrogen, 19.5 per cent. of carbon, 6.5 per cent. of combined chlorine and 45 per cent. of calcium. According to another analysis, nitrogen-lime contains 18.55 per cent. of nitrogen and 5.81 per cent. of calcium chloride. Since, however, it is hygroscopic, the percentage of nitrogen found would depend upon the length of time the sample had been exposed to the air. Both products are fine black powders which smell strongly of acetylene owing to the undecomposed carbide they contain.

With regard to the application of these two new manures certain definite rules must be followed in order to get satisfactory results, and as yet some of the conclusions which have been drawn from experiments both on a small and large scale are somewhat contradictory. Although, when calcium cyanamide was first used, it was thought that the acetylene and its condensation products, generated from the residual carbide by the action of the moisture of the air, might exercise a harmful effect upon the germinating seed or the young crop, these fears have been found to be groundless, for according to Dr. Frank acetylene is not poisonous to plants. Remy states that cyanamide is most suitable for heavy and clayey soils, for which it may be regarded as only slightly inferior to Chili saltpetre. It is stated that the after effects of nitrolim are far greater than those of any other nitrogenous manure. Thus any unused sodium nitrate is washed away and lost by the action of rain, whereas the decomposition of nitrolim yields ammonia, which is fixed by the vegetable mould and is available for a second crop if not used by the first. On the other hand, it is far less effective on sand soils and may even retard the development and growth of the seedling. It has also a bad effect upon the azoto-bacteria, and they will not develop even on re-infection three months after sowing, although when this period has elapsed no ill effects upon the seedling are observed. All experiments show that the fertiliser must not be put upon the ground at the same time as the seeds are sown, but must be well distributed over and mixed with the soil some weeks

before sowing. Otherwise the seedling is injured by it. This injurious effect is either due to the ammonia which is generated from the cyanamide, or else it must be ascribed to the formation of dicyanamide, especially in soils containing much humus, by the polymerisation of cyanamide; hence some authorities consider that the manure should be applied in such a way as to hinder the formation of dicyanamide. On the other hand, experiments performed by Ulpiani seem to show that cyanamide and its calcium salt act as poisons to the plant, preventing the germination of the seed and killing the young plant, while dicyanamide, which results when concentrated solutions of cyanamide are evaporated, favours the development of the plant, and any factor which increases or hastens the polymerisation will also increase the value of the manure. Stoklasa has investigated the conditions which influence the decomposition of calcium cyanamide, and has found that the amount of water and air in the soil have important effects. The cyanamide must be decomposed by bacteria, and if these are absent, as in sandy soils, the fertiliser gives negative results. Löhns found that calcium cyanamide is converted into ammonia in the soil by bacteria such as *B. megatherium* and others, and ammonia is oxidised to nitrates by similar agents.

Sebelien has carried out a series of pot experiments on the comparative effects of different nitrogenous manures on plants and has obtained interesting results. He finds that with oats the effect of calcium cyanamide is about 75 per cent. of that of Chili saltpetre. In field experiments Larsen showed that occasionally calcium cyanamide has a bad effect upon oats, nitrate of lime and Chili saltpetre being of about equal values as fertilisers. With hay calcium cyanamide produced about 69 per cent. of the result of either nitrate of lime or Chili saltpetre.

The amount of cyanamide to be applied per acre depends upon many variable factors, such as the nature and condition of the soil, the crops, etc., but the average amount recommended is from 125 to 225 of lime-nitrogen per acre. In some of the culture experiments the upper limit was considerably exceeded, which might provide an explanation of the ill effects produced.

APPENDIX.

THE Appendix forms a repertory of all the information required in passing from the domain of theory to that of practice. It consists of:—

- I. A Chemical Description of the Ingredients which enter into the Composition of Chemical Manures.*
- II. Practical Instructions for the Preparation, Preservation and Use of Chemical Manures.*
- III. List of Manures, in Order of Succession, best suited for the principal alternations of Crops.*
- IV. Instructions for the Establishment of Experimental Fields for the Analysis of the Soil.*
- V. Tables for Calculating the Exhaustion of the Soil, and for Regulating the Feeding of Live Stock.*
- VI. Description and Illustrations of the Comparative Action of the different Fertilising Agents on the Growth of Plants.*
- VII. Illustrations showing the Comparative Action of Constituents of Plant Production.*

I.

CHEMICAL DESCRIPTION OF THE INGREDIENTS WHICH ENTER INTO THE COMPOSITION OF CHEMICAL MANURES.

Nitrogenous Matter.

All products of vegetable or animal origin, of which nitrogen forms a part, are called by this name.

Blood
Albumen
Hoof and horn waste
Wool waste

Muscular tissue
Fæcal matter
Litter
Oil-cake

are all nitrogenous matter. To act upon vegetation, nitrogenous matter of all kinds must be capable of decomposition in the soil; unless this decomposition takes place, it will have no action upon the plants. When nitrogenous matter is decomposed part of the nitrogen passes into ammonia, or a nitrate of some kind. For this reason, amongst nitrogenous matter suitable for agriculture, we class

Ammonic sulphate

Potassic nitrate

Sodic nitrate

These substances, which are true salts, contain nitrogen amongst their constituents. In ammonic sulphate the nitrogen is present as part of the ammonia, which is the base of the salt; in potassic and sodic nitrates it is contained in the acid of the salt.

Ammonic Sulphate.

This salt is formed of sulphuric acid and ammonia :—

	Per cent.
Sulphuric acid	60·60
Ammonia	25·76
Water	13·64
	<hr/>
	100·00

And as the ammonia in its turn is formed of

Nitrogen	14
Hydrogen	3
	<hr/>
	17

it follows that ammoniac sulphate contains 21·21 per cent. of nitrogen when it is chemically pure.

The ammoniac sulphate of commerce contains at most 20 per cent. of nitrogen.

Ammonia is procured chiefly from the ammoniacal liquors of gas works. It is also obtained in considerable quantities from the destructive distillation of shale, and from blast furnaces and coke ovens. The greatest source of all is volcanoes during their quiescent period, when they send forth nothing but vapour. Unfortunately this source has hitherto been neglected.

It is generally nearly pure, ordinary commercial samples being guaranteed to contain not less than 19·8 per cent. of nitrogen. Ammoniac sulphate owes its efficacy to the nitrogen it contains, and it is a product whose action is fairly rapid if the soil be at all moist and warm, a quality which may be turned to the best account, but it is one that must be used with great prudence. The most suitable quantity to use is from 1 to $1\frac{1}{2}$ cwts. per acre, when only chemical manures are employed. But this product is of the greatest use when it is a question of saving a crop endangered by a too severe winter. About 1 cwt. of ammoniac sulphate, applied in the month of March, will cause the crop to spring up as if by magic. Ammoniac sulphate is, again, of the greatest help in increasing the crop of grain without detriment to the straw. To obtain this result it is only necessary to give to cereals about $\frac{1}{2}$ cwt. of the sulphate per acre, at the end of the month of March, provided always that the soil has been properly prepared and manured in the autumn.

In explanation of this remarkable effect, which, more than any other, shows the great practical importance of the quantity and composition of the manures applied, I will repeat what I have already said in the course of my lectures. Plant life consists of three distinct periods: 1. The embryonic period, during which the young plant lives at the expense of the seed. 2. The foliaceous period, which is essentially the creative period of the crop, during which the plant lives on the air and soil. 3. The reproductive period, during which the plant forms its seed and lives at its own expense. This epoch in the life of the plant I have also called the reabsorptive period, to mark distinctly that the activity of the plant is then removed, and concentrated in the flower and fruit, the formation of which is brought about by means of the substances accumulated in the leaves and stem. Now, at the close of winter, the substance of a part of the leaves has been partially changed by the action of the cold, and vegetation is retarded by the nutritive elements, nitrogen, phosphoric acid, potash and lime, having a tendency to withdraw from the work of vegetation, when they are, of course, lost to the whole vegetable system. A small quantity of ammoniac sulphate will be sufficient to revive the vitality of the leaves, and cause these substances to contribute to the production

of the seed. But for this effect to be obtained the proportion of ammoniac sulphate which I have recommended must not be exceeded, or the leaves will receive an increase of activity, and the whole foliaceous system then becomes so suddenly developed that the formation of the seed is retarded and impaired and the harvest injured, the seed under these conditions being never well formed; besides which the plant is exposed to the worst accident that can befall it, that of laying.

There are, then, two entirely distinct cases to be considered:

1. One in which a blighted or insufficient crop has to be revived.
2. The other, in which the amount of seed has simply to be increased. The rule to be followed in these two cases is now known.

The judicious use of ammoniac sulphate is no less beneficial to permanent meadow land. Small quantities applied four or five times a year tend to promote the formation of the grass, and also to render it more nitrogenous, and consequently more nutritious; from $\frac{1}{4}$ to $\frac{1}{2}$ cwt. about four times a year is a suitable quantity.

The day when we succeed in obtaining ammoniac sulphate from the nitrogen of the atmosphere will mark a new epoch in the history of the world, and the farmer will then be on a level with the chemical manufacturer, in being able to produce the substances necessary for carrying on his work at the cheapest possible price; for this reason, that nitrogen being the dominant ingredient in all crops, a fall in the price of ammoniac sulphate will bring about a corresponding fall in the price of bread and meat.

A wise farmer ought never to buy ammoniac sulphate without having it analysed to ascertain that it contains at least $19\frac{1}{2}$ per cent. of nitrogen.

Sulphate of ammonia gives the best results upon soils of a light or loamy character where nitrification goes on freely; on clay soils it is best replaced by nitrate of soda.

Moreover, it should not be used upon soils deficient in lime, as it leads to the removal of the latter in the form of calcium sulphate and the land becomes acid and unsuitable for the growth of crops.

Sodic Nitrate.

Sodic nitrate is formed of nitric acid and soda. Its exact composition is as follows:—

						Per cent.
Nitric acid	.	.	.	.	.	63·53
Soda	.	.	.	.	.	36·47
						<hr/>
						100·00

It follows that sodic nitrate contains 16·4 per cent. of nitrogen when it is chemically pure. That of commerce contains from 14 to 15 per cent. Sodic nitrate is obtained from Peru, where it is found in the form of compact masses mixed with sand and sea-salt.

The sodic nitrate of commerce is never pure, it contains from 4 to 5 per cent. of foreign matter, represented generally by sodic chloride and moisture. Its composition fluctuates within the following limits:—

	Minimum	Maximum	Average
Sodic nitrate . . .	94.56	96.45	95.45
Sodic chloride . . .	0.95	3.41	1.62
Moisture . . .	1.90	2.85	2.25

The mean standard in nitrogen is 15.7 per cent., and it is generally guaranteed to contain not less than this amount. It is advisable to have the salt analysed before it is purchased.

Sodic nitrate is used in the same way as ammoniac sulphate, but for the proportion of nitrogen to be equal the quantity of sodic nitrate must be increased one-fourth, 125 lbs. of sodic nitrate for 100 lbs. of ammoniac sulphate. With cereals sodic nitrate produces more leaves and less grain, but for root crops—turnips, beetroot, etc.—it should have the preference over ammoniac sulphate. When the summer has been dry, and the root crops have suffered, 264 lbs. per acre of sodic nitrate, applied in the month of July, will restore the crop if the months of August and September are at all rainy. When sodic nitrate is used for cereals it is well to give one-fifth less nitrogen than with ammoniac sulphate.

All these products are, on account of their great richness in nitrogen, very active, and therefore require to be spread over the land with great care. The best method is to mix them with two or three times their weight of fine moist earth, making the whole into a heap, which is left for two or three days, and then spread by hand, or by means of appropriate machines. The cost of hand-labour is largely compensated for by the excess of the crop.

The earthquakes which of late years have occurred on the Peruvian coast have diminished the importation of sodic nitrate, and caused it to rise in price. The Peruvian Government has also levied a duty on its export, which prevents exportation. This has been done with the double object of increasing the revenue and protecting guano. Another unwelcome fact is that, being in the hands of a very small number of merchants, sodic nitrate has become a real object of speculation.

Nitrate of Lime.

This is a new fertiliser, the nitrogen of which is derived from the air (see Lect. XVI.).

It is a brownish compound readily soluble in water and has a rapid beneficial effect upon crops of all kinds.

As sent into commerce it contains from 75 to 77 per cent. of calcium nitrate— $\text{Ca}(\text{NO}_3)_2$ —equivalent to about 13 per cent. of nitrogen; and 20 to 25 per cent. of lime also.

For soils deficient in lime it is an excellent manure, and

experiments in various parts of the country have shown that its nitrogen is as effective as that of nitrate of soda.

Calcium Cyanamide or "Nitrolim".

Like the preceding substance this is a new nitrogenous fertiliser which has been placed upon the market under the trade name "nitrolim". Its nitrogen is derived from the air in the manner described in Lect. XVI.

"Nitrolim" contains 20 per cent. of nitrogen—about the same amount as that in sulphate of ammonia—and 18 per cent. of useful free lime. When added to the soil it undergoes change, the nitrogen ultimately taking the form of a nitrate.

It has a somewhat deleterious action on young plants and is therefore not so useful for top dressings as some of the other nitrogenous manures. "Nitrolim" should be applied eight or ten days before the seed is sown, wherever possible.

Potassic Nitrate.

This salt, which is also called nitre, or saltpetre, is formed of nitric acid and potash:—

						Per cent.
Nitric acid	.	.	.	.	.	53·41
Potash	.	.	.	.	.	46·59
						<hr/> 100·00

At the rate of fourteen parts of nitrogen to four of nitric acid, it contains 13·8 per cent. of nitrogen in the pure state, but that of commerce contains only from 12 to 13 per cent. Potassic nitrate is obtained—in large sheds built for the purpose—by the decomposition of animal matter mixed with clayey or marly soil, which is then washed to extract the nitre. For a long time this salt was obtained from waste building materials. It is now made by decomposing potassic chloride by means of sodic nitrate; sodic chloride (sea-salt) and potassic nitrate are obtained at the same time, but they are easily separated by crystallisation. Of all the products that contain potash, potassic nitrate is most suitable for agricultural purposes.¹

Potassic nitrate is one of the most efficacious agents in the growth of plants. It contains nitrogen and potash in a very assimilable form, and for certain plants, such as tobacco, it is the most suitable in many respects. For other plants, in which potash is the dominant constituent, but which do not require nitrogen, such as peas, beans, sainfoin or clover, potassic chloride is to be preferred, whilst for other plants whose dominant is nitrogenous matter, such as cereals and meadow grass, potassic chloride mixed with ammoniac

¹ Its price, however, is prohibitive for use as a fertiliser for agricultural purposes. For gardens it may be used profitably perhaps in small quantities.

sulphate can be advantageously substituted for potassic nitrate. In this case, 100 lbs. of potassic chloride at 80°, and 75 lbs. of ammoniac sulphate, are used instead of 100 lbs. of potassic nitrate. Potassic nitrate is often adulterated with chlorides and alkaline sulphates, or even with sodic nitrate. In the latter case the salt contains the necessary quantity of nitrogen, and the adulteration affects the potash only; it is therefore necessary that this product should be analysed by a chemist before it is used.

Potassic Chloride.

In 100 parts, potassic chloride contains :—

	Per cent.
Potassium	52·41
Chlorine	47·59
	<hr/> 100 00

52·41 of potassium corresponding to 63·16 of potash.

Potassic sulphate can also be used, but I have obtained less favourable results with this salt than with potassic chloride, and it is generally dearer.

Since the discovery of the Stassfurth mines the price of this salt cannot fluctuate much, as the supply exceeds the demand.

Kainit.

For the purpose of supplying potash to the soil kainit is now largely used. It is a natural product obtained in mines near Stassfurth in Germany, and consists largely of sulphates of potash and magnesium with chlorides of sodium (common salt) and magnesium.

The amount of potash (K_2O) present usually amounts to 12·5 per cent., equivalent to about 23 or 24 per cent. of sulphate of potash; the amount of common salt in it is about 34 per cent.

Kainit is a useful manure on many light, sandy, peaty or chalky soils and gravelly land, and should be applied in autumn at the rate of 2 to 3 cwts. per acre.

Potassium Sulphate.

From kainit a more concentrated potash fertiliser is prepared, consisting of the sulphates of potassium and magnesium.

Ordinary samples contain 48 to 52 per cent. of potassium sulphate, which is equivalent to 26 to 28 per cent. of potash (K_2O).

A purer form of potassium sulphate is put on the market, also prepared from kainit, and containing 90 to 96 per cent. of the compound (equal to $48\frac{1}{2}$ to 52 per cent. of potash, K_2O).

This is a valuable fertiliser on light soils. It is less bulky than kainit, costing less for carriage and contains no salt or other chlorides which are detrimental to the growth of some plants.

Amounts of $\frac{1}{2}$ to 1 cwt. per acre may be applied in mixtures where potash is a desirable constituent.

Calcic Phosphate.

Under the name of calcic phosphate a large number of different products are comprehended. For a long time nothing but the calcic phosphate obtained from bones, mixed with calcic carbonate, was used for agricultural purposes. At the present time the greater part of the phosphates used as manure are obtained from the mineral kingdom, where they are found in practically inexhaustible quantities. All the phosphates used in agriculture are formed of phosphoric acid and lime. Phosphoric acid itself is formed of phosphorus and oxygen :—

Phosphorus	31
Oxygen	40
	<hr/>
	71

In phosphates it is the phosphoric acid which is the active part. Chemists are accustomed to represent phosphoric acid by the symbol H_3PO_4 . We know of four principal sorts of calcic phosphate. The *tetracalcic phosphate* in basic slag has the formula— $Ca_3_2PO_4 \cdot CaO$; the *tricalcic phosphate* has the formula— $Ca_3_2PO_4$, and the *dicalcic phosphate* has the formula—



The most important phosphate— $CaH_4_2PO_4$ —has received the name of superphosphate of lime. It is prepared, commercially, by treating bones, or mineral phosphates, with sulphuric acid. The acid phosphate is thus mixed with calcic sulphate, and under this form receives the name of superphosphate of lime or calcic superphosphate. It contains from 15 to 18 per cent. of phosphoric acid per cwt.

I shall not enter into any particulars as to the manufacture of this product, though it is advisable that agriculturists should know how to make it for themselves. I shall devote a special manual to this subject, and for the present look only at the effects of calcic superphosphate on vegetation.

Of the various sources of phosphoric acid, the superphosphate is to be preferred, as, on account of its solubility in water, the phosphoric acid of the superphosphate is most readily diffused through the soil. The proportions of phosphoric acid being equal, it produces greater effect than the phosphate containing either two or three equivalents of lime on those plants whose dominant constituent is phosphoric acid, such as turnips, swedes, maize and sugarcane, and with a smaller proportion the result is at least equal.

There are, however, two cases in which bi- and tricalcic phosphates are more beneficial, viz., on newly cleared land and on damp

meadows. The blackish matter that the earth then contains assists the solution of the phosphates so much that the superphosphate is in part carried off by the waters, and the phosphates containing two or three equivalents are also attacked with remarkable certainty, but resist being carried off by the water. In the majority of instances the bicalcic phosphate answers better than the tricalcic, its effect being more sure and its assimilability greater. But the natural phosphates, better known by the name of coprolites, can sometimes be used with advantage on newly cleared land and damp meadows; in this case the phosphate must be spread as a manure on animal litter, or, in other words, it must always be associated with animal manure. If this condition is not fulfilled, and the phosphates are to be used by themselves or with chemical manures, the superphosphates are preferable to the two other forms. It must, however, be specially noted that superphosphate of lime should not be *mixed* with nitrate of soda; these two manures, however, may be applied to the land separately. In a cold and damp climate, like that of England, great advantage is to be gained by the free use of phosphate.

In the state of coprolites calcic phosphate is mixed with 40 or 50 per cent. of foreign matter.

Basic Superphosphate.

Ordinary superphosphate of lime is an acid manure which upon light soils and certain clays containing little or no lime is not so desirable as those of neutral or alkaline nature. Moreover, club-root, or "finger-and-toe" disease of turnips is encouraged by acid manures.

A basic superphosphate, suitable for use on soils of these types, is now on the market, produced by the addition of lime to ordinary superphosphate. The phosphate in it, although not so soluble as the compound present in superphosphate, is easily dissolved by the organic acids of the soil and becomes readily available to plants.

It contains about 12 or 13 per cent. of phosphoric acid, equal to 26 or 28 per cent. of phosphate of lime.

Basic Slag.

One of the most important additions to the list of manures capable of supplying phosphates to the soil for the nutrition of crops is basic slag, Thomas phosphate or basic cinder as it is sometimes called. It is a by-product in the manufacture of steel from pig-iron containing phosphorus.

A great many iron ores used for the making of pig-iron contain a small percentage of phosphorus. During the smelting process this element combines with the iron, and if more than about $\frac{1}{2}$ per cent. is present the resulting phosphorised pig-iron cannot be used for the production of steel by the ordinary Bessemer process,

on account of the fact that steel made from such iron becomes brittle and liable to fracture when hammered in a cold state.

In the Thomas-Gilchrist improvement of the Bessemer process, the elimination of the objectionable phosphorus is secured by lining the converters in which the iron is melted with limestone and by the addition to the molten metal of quantities of quicklime. At a certain stage air is driven through the molten metal, the phosphorus being oxidised to phosphoric acid, which combines with the lime to form a phosphate of lime. The latter compound ultimately rises to the surface of the molten metal, and, becoming mixed or combined with the slag floating there, forms basic slag which is poured off and cooled.

When first obtained the slag was cast aside as useless and accumulated to a large extent round steel works in various parts of the country.

On the assumption that the phosphorus existed in the slag as ordinary tribasic calcium phosphate ($(\text{CaO})_3\text{P}_2\text{O}_5$), attempts were made to utilise it for the manufacture of superphosphate and similar fertilisers, but the cost of using it in this manner was prohibitive. Later it was discovered that much of the phosphorus was present in the form of tetrabasic phosphate of lime $(\text{CaO})_4\text{P}_2\text{O}_5$, which, instead of being as insoluble as the tribasic compound, was readily soluble in weak acid in the soil when applied in the form of a fine powder.

Wagner in Germany and Wrightson and Munro in England experimented with the finely ground basic slag about 1884, and showed that it had a very striking influence upon crops, especially those of the leguminous order. Since that time its use has spread extensively, so that at present over 2,000,000 tons are used annually as a fertiliser, the greatest consumer and manufacturer of it being Germany.

The composition of basic slag in respect of the useful phosphate it contains depends upon the composition of the iron ore and the materials added to the molten metal. The amount of phosphorus calculated as phosphoric acid varies from about 12 to nearly 23 per cent., which is equivalent to 26 to about 50 per cent. tribasic phosphate of lime. Its beneficial action is in part due to the lime it contains. Before it can be used as a fertiliser, it must be ground into an almost impalpable powder; it is usually sold with a guarantee of being fine enough for 85 per cent. of it to pass through a sieve having 10,000 holes in a square inch. If much coarser than this it is only slowly dissolved in the soil and is consequently slow in its action upon crops.

Unlike superphosphate, which is an acid manure, basic slag is alkaline. It does best on moist clays and loams, and on peaty soils deficient in lime, but can be used on light soils in some cases, especially where kainit or other potash manure is used with it.

It should be applied to the land in autumn and winter, from November to end of January being the usual time for spreading it.

Basic slag must not be mixed with ammonium sulphate, since it drives off valuable ammonia from the latter.

Like all phosphatic fertilisers, it is specially adapted to the needs of beans, peas, clover and other leguminous crops.

It may be used with advantage also for the growth of turnips and swedes where "finger-and-toe" disease is prevalent, since its alkaline character and the lime it contains both tend to check the trouble. It is frequently found that upon light land basic slag has very little effect either on grass or ordinary arable crops. This is in many cases less on account of want of potash and nitrogen than on any defect of the slag. A combination of slag with kainit or sulphate of potash usually gives good results.

Perhaps the chief use to which basic slag is applied with the most remarkable results is for the improvement of the herbage of poor worn-out meadows and pastures upon stiff soils.

An application of from 5 to 10 cwts. per acre is found to stimulate in an almost magical way the growth of clover and other leguminous plants of pasture. On impoverished and acid land white clover is repressed and stunted, so much that it is difficult to find it without careful search.

After basic slag is applied the soil becomes more adapted to the growth of the clover, and it asserts itself above the grasses, among which it has been almost smothered.

The good effect of one dressing of 10 cwts. of slag lasts several years. Not only is the quantity of the herbage increased, but its quality as food for stock is vastly improved.

In some experiments at Cockle Park, Northumberland, sheep were fed upon plots receiving no manure and 10 cwts. basic slag respectively. On the unmanured plot the live-weight increase was 182 lbs.; on the manured plot the increase was 590 lbs. for the same period.

Purchasers should be on their guard against fraudulent offers of slags containing practically no phosphates or other useful fertilising constituents. Ordinary iron and steel slags are of this class, and are quite useless no matter how finely ground; only those resulting from the Thomas-Gilchrist and similar processes are of value for agricultural purposes.

Calcic Sulphate.

Calcic sulphate is nothing more than unburnt plaster of Paris or gypsum, and is composed of sulphuric acid and lime. It is found in nature in large quantities in the form of hydrate—

	Per cent.
Sulphuric acid	46.51
Lime	32.56
Water	20.93
	<hr/>
	100.00

Exposed to a temperature of 248° to 266° F. it loses its water and passes into the state of anhydrous sulphate, more commonly known as plaster of Paris. In using calcic sulphate I prefer it in this state. It can also be used in the form of raw gypsum, only in this case the proportion must be increased by one-fifth.

II.

PRACTICAL INSTRUCTIONS ON THE PRESERVATION, PREPARATION AND EMPLOYMENT OF CHEMICAL MANURES.

As a general rule chemical manures must be kept in a dry place—a barn for instance. The operation of mixing the various products, without being difficult, requires some care.

It is necessary, in the first place, that they should be thoroughly mixed, for if this condition be not fulfilled the rootlets of the plants will not find within their reach the different agents whose good effects depend partly upon their simultaneous presence.

In making the mixture the calcic superphosphate should be in a dry state. When it is first prepared this substance has a pasty consistence that renders mixing difficult, but at the end of two or three months it dries and falls into powder.

The following is the mode of procedure: The calcic phosphate is first spread over the surface of a hard piece of ground and covered with the gypsum. After twenty-four hours the two products are mixed with a spade into little heaps and left for a day or two. The first mixture is then spread afresh on the floor, and the other products are thoroughly incorporated by means of a vigorous use of the spade, the effect of which is completed by beating the agglomerated masses with a large-headed rammer, which can be constructed by fixing an upright handle in the middle of a piece of board eight or ten inches long by four in thickness. The mixture being completed, it is absolutely necessary that it should be passed through a sieve and stirred afresh. It must, however, be understood that this applies only to small farming; when operations are carried on on a larger scale the mixing must be done by machinery. With a two-horse-power engine it is easy to prepare 30 or 40 tons of mixture. The machine is provided both with stones for crushing the products and sieves to separate the uncrushed parts.

We give below an illustration of a machine of this kind,¹ which is largely used in France, both by manufacturers of chemical manure and also by agriculturists themselves.

These directions must be strictly observed, for if a manure is to

¹These machines may be procured from J. M. Fleury, 91 Rue de Crimée à la Villette, Paris.

produce its full effects, each filament of the root must be able to absorb at the same time all the substances that enter into its composition, and this result cannot be obtained unless the mixture is homogeneous. The spreading of chemical manures also requires particular care. The best way is, unquestionably, to make use of one of the excellent machines that we now possess for spreading pulverised manure, for with them the result leaves nothing to be desired.

When I add that if the dressing be properly performed it will increase the yield by two or three bushels of grain per acre, you will see how important it is to use the greatest care.

For those who do not possess a machine, and who have to effect this operation by hand, the best way is to mix the manure with an equal amount of fine dry earth, and throw it broadcast over the land like seed. When this method is followed the manure

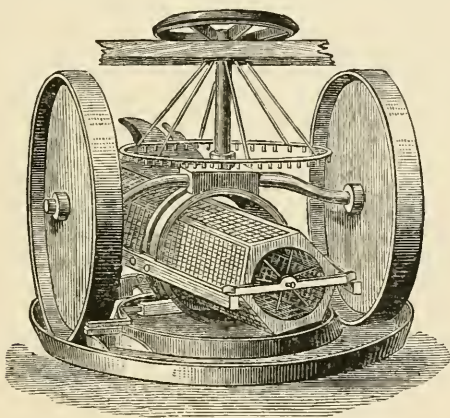


FIG. 7.

must first be divided into a certain number of little heaps, which are distributed over the plots of ground for which they are destined. If we have to deal with cereals, peas or beans, the manure must be spread after the last ploughing, and its exact division over the surface of the soil ensured by means of careful harrowing.

For plants with tap roots which burrow to a great depth, it is preferable to spread the manure twice, half after the first ploughing and half after the last. For vines I have found the following method best: The manure is spread upon the soil around each vine; it is then well dug into the ground with the spade or with the plough. Vines ought to be manured in the autumn. For hay I believe it is better to spread half the manure in the autumn and half in the spring, after the first cutting. When we spread the manure broadcast one precaution is necessary, *viz.*, to work in a calm day, if it is windy we are apt to lose a good deal.

I will not repeat what I have already said of the advantages that chemical manures possess over stable manures, but I ought to insist on the resources they afford in combating the effects of an unfavourable year. When the winter has been severe, and is prolonged beyond the usual limits, wheat, and other cereals generally, are often much affected. With from 330 to 440 lbs. of ammoniac sulphate, or 440 lbs. of sodic nitrate mixed with 440 lbs. of gypsum, which is spread as a covering at the beginning of March, we can in a few days change the state of the culture and ensure a successful crop. The effect of these manures, as a top dressing, is truly magical.

But here, again, certain precautions must be taken; it will not do to apply this dressing later than the middle of March. Used in April or May it gives extraordinary activity to vegetation, but it retards the ripening of the grain, and on account of the exaggerated development of the straw the grain is ill formed, less abundant and stunted. By the certainty and rapidity of the action of these manures, when used as a top dressing, they are a source of inestimable value to the farmer. When the autumn is wet and sowing is delayed, to save time the manure can be spread as a dressing after the seed has sprung up. It is certainly better to give the dressing before sowing, but when unable to do that there need be no hesitation. One dose of manure as a top dressing will suffice to ensure the success of the crop, whilst with animal manure this expedient would result in a complete failure.

In the spring we need only employ as a dressing ammoniac sulphate or sodic nitrate. The two products will be found quite sufficient. I, however, prefer to add to them 440 lbs. of superphosphate mixed with 440 lbs. of gypsum per acre.

III.

COLLECTION OF FORMULÆ FOR THE CHEMICAL MANURES MOST USED, WHETHER ALONE OR IN COMBINATION WITH FARMYARD MANURE.

IN order to facilitate inquiry and comparison, the best formulæ for those manures which are fittest for crops grown on the rotation system are given in the following chapter.

By dividing the application of the manure over several years instead of using it all at the beginning, we gain a double advantage, as we not only reduce our expenses during the first year, but we obtain an increased yield. The following formulæ have been devised specially to suit this method of application.

The matter is considered from two distinct points of view ; one, in which chemical manure only is employed, the other in which it is used in combination with other manures, no matter whether crops are grown in rotation or continuously.

First Case.

IN WHICH CHEMICAL MANURE IS USED ALONE WITHOUT THE ADDITION OF FARMYARD MANURE.

Single Crop.

WHEAT.

	Per acre lbs.
Normal manure, No. 1	
Calcic superphosphate . . .	176
Potassic sulphate, at 80° . . .	88
Ammonic sulphate . . .	171

In Spring.

Nothing, or ammonic sulphate, 44, 88, or 132 lbs.

Barley, Oats, Rye, Natural Meadow.

	Per acre lbs.
Normal manure, No. 1	
Calcic superphosphate . . .	176
Potassic sulphate, at 80° . . .	88
Ammonic sulphate . . .	171

For meadow land we may apply the manure in two different ways, either all at once in autumn, or half in the autumn and half in the spring, after the first crop of hay has been cut.

If the oat crop appears too light, a further quantity of 44 or 88 lbs. of ammonic sulphate must be added in the month of April.

Hemp and Colza.

	Per acre lbs.
Normal manure, No. 1	870

If the colza is to be followed by a wheat crop, we must use the second year,

	Per acre lbs.
Ammonic sulphate	264

Beetroot, Carrots, Cabbages, Hops, Garden Stuff.

	Per acre lbs.
Normal manure, No. 2	
Calcic superphosphate	352
Potassic sulphate	88
Sodic nitrate	264

In the case of beetroot, if we wish to obtain the largest possible yield, the normal stimulating manure, No. 2, must be substituted for the above.

	Per acre lbs.
Normal stimulating manure, No. 2	
Calcic superphosphate	352
Potassic sulphate	88
Sodic nitrate	396

Potatoes.

	Per acre lbs.
Normal manure, No. 3	
Calcic superphosphate	352
Sodium nitrate	264
Potassium sulphate	168

With exhausted soils 1,056 lbs. per acre of normal manure, No. 2, should be used.

Vines and Fruit Trees.

	Per acre lbs.
Normal manure, No. 4	
Calcic superphosphate	528
Sodium nitrate	214
Potassium sulphate	224

Normal manure, No. 2, gives very good results in vineyards which hitherto have only produced grapes of ordinary quality. It is as well, therefore, to begin with it.

Turnips, Swedes, Jerusalem Artichokes, Sorghum, Sugar-cane, Maize.

	Per acre lbs.
Normal manure, No. 5	
Calcic superphosphate	528
Sodium nitrate	176
Potassium sulphate	168

Beans, Horse-beans, Haricot, Clover, Sainfoin, Tares, Lucern.

	Per acre lbs.
Incomplete manure, No. 6	
Calcic superphosphate	352
Potassic sulphate, at 80°	168

The following are adapted to crops grown in rotation:—

ALTERNATE CULTIVATION OF COLZA AND WHEAT.

First Year.

COLZA.

	Per acre lbs.
Normal manure, No. 1	
Calcic superphosphate	352
Potassic sulphate	168
Ammonic sulphate	220

Second Year.

WHEAT.

	Per acre lbs.
Ammonic sulphate	264
Ashes of haulm and pods of colza	—

The haulm and pods of the colza may be burnt on the field itself, and scattered over the surface after the first ploughing, the ammonic sulphate being ploughed in afterwards. Instead of burning the haulm it may be thrown on the dung-heap, according to the directions given in the sixth lecture.

ROTATION OF CROPS FOR FOUR YEARS.

POTATOES, WHEAT, CLOVER, WHEAT.

First Year.

POTATOES.

	Per acre lbs.
Normal manure, No. 3	
Calcic superphosphate	352
Sodium nitrate	264
Potassium sulphate	168

Second Year.

WHEAT.

Ammonic sulphate	264
--------------------------	-----

Third Year.

CLOVER.

Incomplete manure, No. 6	
Calcic superphosphate	352
Potassic sulphate, at 80°	168

Fourth Year.

WHEAT.

Ammonic sulphate	264
--------------------------	-----

ROTATION OF CROPS FOR FOUR YEARS.

BEETROOT, WHEAT, CLOVER, WHEAT.

First Year.

BEETROOT.

	Per acre lbs.
Normal manure, No. 2	
Calcic superphosphate	352
Potassic sulphate	88
Sodic nitrate	264

Second Year.

WHEAT.

Ammonic sulphate	264
--------------------------	-----

Third Year.

CLOVER.

	Per acre lbs.
Incomplete manure, No. 6	
Calcic superphosphate	352
Potassic sulphate, at 80°	168

Fourth Year.

WHEAT.

Ammonic sulphate	264
----------------------------	-----

ROTATION FOR FIVE YEARS.

POTATOES, WHEAT, CLOVER, COLZA, WHEAT.

First Year.

POTATOES.

	Per acre lbs.
Normal manure, No. 3	
Calcic superphosphate	352
Sodium nitrate	264
Potassium sulphate	168

Second Year.

WHEAT.

Ammonic sulphate	264
----------------------------	-----

Third Year.

CLOVER.

Incomplete manure, No. 6	
Calcic superphosphate	352
Potassic sulphate, at 80°	168

Fourth Year.

COLZA.

Ammonic sulphate	352
----------------------------	-----

Fifth Year.

WHEAT.

Ammonic sulphate	264
----------------------------	-----

ROTATION OF CROPS FOR TWO YEARS.

MAIZE, WHEAT.

First Year.

MAIZE.				Per acre lbs.
Normal manure, No. 5				
Calcic superphosphate	.	.	.	528
Sodium nitrate	.	.	.	176
Potassium sulphate	.	.	.	168

Second Year.

WHEAT.

Ammonic sulphate	264
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ROTATION FOR SIX YEARS.

FLAX, BEETROOT, WHEAT, COLZA, WHEAT, OATS, RYE, OR
BARLEY.*First Year.*

FLAX.				Per acre lbs.
Normal manure, No. 6				
Calcic superphosphate	.	.	.	352
Sodium nitrate	.	.	.	176
Potassium sulphate	.	.	.	88

Second Year.

BEETROOT.

Normal manure, No. 2				
Calcic superphosphate	.	.	.	352
Potassic sulphate	.	.	.	88
Sodic nitrate	.	.	.	264

Third Year.

WHEAT.

Ammonic sulphate	264
------------------	---	---	---	---	-----

Fourth Year.

COLZA.

Normal manure, No. 1				
Calcic superphosphate	.	.	.	176
Potassic sulphate	.	.	.	88
Ammonic sulphate	.	.	.	171

Fifth Year.

WHEAT.

Ammonic sulphate	264
------------------	---	---	---	---	-----

Sixth Year.

OATS, RYE, OR BARLEY.

Ammonic sulphate	176
------------------	---	---	---	---	-----

ROTATION OF CROPS GROWN FOR FODDER.

First Year.

WHEAT.

	Per acre lbs.
Normal manure, No. 1	
Calcic superphosphate	176
Potassic sulphate	88
Ammonic sulphate	171

Second Year.

CLOVER.

Incomplete manure, No. 6	
Calcic superphosphate	352
Potassic sulphate, at 80°	168

Third Year.

WHEAT.

Ammonic sulphate	264
----------------------------	-----

Fourth Year.

TARES, BEANS AND MAIZE.

Incomplete manure, No. 6	
Calcic superphosphate	352
Potassic sulphate, at 80°	168

Fifth Year.

WHEAT.

Ammonic sulphate	264
----------------------------	-----

Sixth Year.

TARES, BEANS AND MAIZE.

Incomplete manure, No. 6	
Calcic superphosphate	352
Potassic sulphate, at 80°	168

MANURE FOR MEADOW LAND.

First Year.

	Per acre lbs.
Incomplete manure, No. 6	
Calcic superphosphate	352
Potassic sulphate, at 80°	168

Second Year.

Ammonic sulphate	264
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Second Case.

IN WHICH CHEMICAL MANURES ARE USED IN COMBINATION WITH FARMYARD MANURE.

When chemical manures are used in combination with stable manure we must look on the latter as a fund of richness possessed by the soil, and confine our use of the chemical manures to those substances which best suit the particular crop grown during the year. For this purpose it is important that we should know the principal mineral ingredient in each plant, information which is furnished in the following table:—

Crop.	Dominant ingredient.	Corresponding chemical products.
Beetroot	Nitrogen	<ul style="list-style-type: none"> { Ammonic sulphate { Sodie nitrate { Potassic nitrate { Calcium nitrate { Calcium cyanamide
Colza		
Wheat		
Barley		
Oats		
Rye		
Meadow land		
Peas	Potash	<ul style="list-style-type: none"> { Potassic nitrate { Purified potash { Potassic silicate { Potassic sulphate { Kainit
Haricots		
Beans		
Clover		
Sainfoin		
Tares		
Lucern		
Flax		
Potatoes		
Turnips	Phosphates	<ul style="list-style-type: none"> { Bone black from <li style="padding-left: 20px;">sugar refinery { Burnt bones { Superphosphate { Raw bones { Steamed bone flour { Dissolved bones { Basic slag { Basic superphosphate
Swedes		
Jerusalem artichokes		
Maize		
Sorgho		
Sugar-cane		

If we use 44 tons of farmyard manure every five years, the following are the chemical manures which we must select:—

ROTATION OF FIVE YEARS.

POTATOES, WHEAT, CLOVER, WHEAT, OATS.

First Year.

POTATOES.					Per acre
Farmyard manure	.	.	.	.	44 tons
Chemical manures					lbs.
Normal manure, No. 6					
Calcic superphosphate	.	.	.	.	176
Potassic sulphate	.	.	.	.	88

Second Year.

WHEAT.

	Per acre lbs.
Ammonic sulphate	176

Third Year.

CLOVER.

Incomplete manure, No. 6	
Calcic superphosphate	352
Potassic sulphate, at 80°	168

Fourth Year.

WHEAT.

Ammonic sulphate	176
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Fifth Year.

OATS.

Ammonic sulphate	244
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ROTATION OF FIVE YEARS.

BEETROOT, WHEAT, CLOVER, WHEAT, OATS.

First Year.

BEETROOT.

	Per acre lbs.
Normal manure, No. 2	
Calcic superphosphate	176
Potassic sulphate	88
Sodic nitrate	132

Second Year.

WHEAT.

Ammonic sulphate	176
----------------------------	-----

Third Year.

CLOVER.

Incomplete manure, No. 6	
Calcic superphosphate	352
Potassic sulphate, at 80°	168

Fourth Year.

WHEAT.

Ammonic sulphate	176
----------------------------	-----

Fifth Year.

OATS.

Ammonic sulphate	264
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ROTATION OF FIVE YEARS.

COLZA, BEETROOT, WHEAT, CLOVER, BEETROOT.

First Year.

COLZA.

	Per acre
	tons
Stable manure	44
	lbs.
Ammonic sulphate	264

Second Year.

BEETROOT.

Normal manure, No. 2	
Ashes of colza haulm and pods of colza	
Calcic superphosphate	176
Potassic sulphate	88
Sodic nitrate	132

Third Year.

WHEAT.

Ammonic sulphate	176
----------------------------	-----

Fourth Year.

CLOVER.

Incomplete manure, No. 6	
Calcic superphosphate	352
Potassic sulphate, at 80°	168

Fifth Year.

WHEAT.

Ammonic sulphate	176
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ROTATION OF SIX YEARS.

FLAX, BEETROOT, WHEAT, COLZA, WHEAT, OATS.

First Year.

FLAX.

	Per acre
	lbs.
Normal manure, No. 6	
Calcic phosphate	352
Sodium nitrate	176
Potassium sulphate	88

Second Year.

BEETROOT.

Stable manure applied in autumn	44 tons
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In Spring.

Normal manure, No. 2	
Calcic superphosphate	176
Potassic sulphate	88
Sodic nitrate	132

Third Year.

WHEAT.

Ammonic sulphate	Per acre lbs. 264
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Fourth Year.

COLZA.

Normal manure, No. 1	
Calcic superphosphate	352
Potassic sulphate	88
Ammonic sulphate	220

Fifth Year.

WHEAT.

Ashes of colza haulm ploughed in early	
Ammonic sulphate	264

Sixth Year.

OATS, RYE, OR BARLEY.

Ammonic sulphate	176
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Before beginning on a large scale it is better to make a number of experiments on several small plots, thereby limiting our expenses to 15s. or 20s.; for what is true of a few square yards is found in practice to be equally true of many acres.

*Strength of the different Ingredients which enter into
Manufacture of Chemical Manures.*

		Phosphoric Acid. Per cent.	Symbol P_2O_5
Sources of phosphoric acid	{ Calcic superphosphate	15	
	{ Precipitated calcic phosphate	32	
	{ Basic superphosphate	15	
	{ Basic slag	12-20	
Sources of potash	{ Potassic nitrate, at 95 per cent.	44	Potash. K_2O
	{ Potassic chloride, at 80 per cent.	50	
	{ Potassic sulphate, at 80 per cent.	43	
	{ Kainit	12½	
Sources of nitrogen	{ Ammonic sulphate, at 95 per cent.	20-30	Nitrogen. N
	{ Sodic nitrate, at 95 per cent.	15-72	
	{ Potassic nitrate, at 95 per cent.	13-00	
	{ Calcium cyanamide	20	
	{ Calcium nitrate	13	
Sources of lime		Lime.	CaO
	{ Calcic sulphate (burnt gypsum) }	38	

It would always be better for farmers to mix their own manures according to the directions already given. By this means we not only economise expense, but we are also absolutely sure of getting what we require.

IV.

PRACTICAL INSTRUCTIONS FOR THE ESTABLISHMENT OF EXPERIMENTAL FIELDS AND FOR THE INTERPRETATION OF THEIR RESULTS.

THE analysis of the soil, from an agricultural point of view, having been fixed and determined by what has been said in the previous lectures, we will now enter on the practical consideration of the question of experimental fields, how they ought to be established, the number of plots they should contain, and the composition of the manures that should be used on them.

I shall consider three distinct cases:—

1. The case of an elementary school. The child must here be taught simple and precise notions with respect to fertilising agents, and a few definite facts should be placed before him.

2. The case of a newly-worked farm, the soil of which must be analysed in order to ascertain exactly the fertilising agents that should be used, and to determine the proper quantities in which to employ them.

3. The case of experimental fields for agricultural colleges and societies. In this case the experimental field must become, in a measure, the living expression of the laws of vegetation.

Experimental Field for an Elementary School.

Plots of about 4 poles—say 11 yards square—are quite large enough; they may be five or ten in number, according to the resources of the school. If they must be restricted to five, they should be placed parallel to each other on the same line, each plot being separated from the other by a path about a yard wide, and the whole surrounded by a narrow roadway about 2 yards wide. If there are ten plots they are placed in two rows and separated as before. In this case the field is arranged in the following manner:—

Farmyard manure.	Normal manure.	Mineral manure, <i>i.e.</i> , with- out nitro- gen.	Nitro- genous matter.	No manure.
Farmyard manure.	Normal manure.	Mineral manure, <i>i.e.</i> , with- out nitro- gen.	Nitro- genous matter.	No manure.

In the first row wheat is cultivated, and in the second potatoes.

What ideas is such a field calculated to impress upon the young mind? Four, all of which are of primary importance:—

1. By the comparison of plots 1 and 2, proof is afforded that from 22 to 26 lbs. of a simple powder produce a larger crop than nearly 8 cwts. of good farmyard manure, and that, thanks to the composition called chemical manure, which may be procured at any time, like cement, plaster, or soap, cultivation becomes a very simple business, regulated in its means and certain in its results.

2. On comparing plots 2 and 3, it will be found that the suppression of a single substance, nitrogenous matter, in the normal manure, which contains four, will be sufficient to reduce very considerably the useful effect of the three others which then compose the manure.

3. That in the generality of soils, nitrogenous matter, used alone, produces more effect than the three minerals, phosphate, potash and lime contained in plot 3, put together.

4. That though extremely efficacious with wheat, nitrogenous matter is much less so with potatoes, and that with this crop the minerals have a decided advantage.

But if at one time it is the nitrogenous matter and at another it is the mineral portion of the chemical manure which is the most beneficial, according to the nature of the plants, it is evident that when farmyard manure is used it is very advantageous to supplement it with nitrogenous matter or minerals when applied to wheat or potatoes, etc.

The conclusions drawn will be:—

That it is possible to farm without using animal manure; that a manure can be and is composed which more than takes its place; and that the action of animal manure is intensified by the addition of chemical manure.

Experimental Field for a newly-worked Farm.

In this particular case two distinct objects present themselves, one of which is to ascertain the nature and composition of the soil, and the other to regulate with certainty the use of the fertilising agents which we must bring in from outside in order to obtain a profit.

The choice of site is a very important condition. A piece of land should, if possible, be selected which, in its physical nature and degree of fertility, represents the average quality of the land that is to be cultivated; moreover, it should be as uniform as possible. The field ought to consist of twenty plots, each containing about four poles, arranged in two parallel rows of ten plots each. The first row should be devoted to the cultivation of wheat, and the second to that of beetroot, mangel or potatoes, according to the climate and the wants of the district. The wheat furnishes indications of the richness of the superficial layers of the soil, and the beetroot or mangel of the deeper layers. Whenever an experimental field admits of two crops being grown, one of wheat and the other some plant that requires to be kept free from weeds, such as beetroot, many advantages are gained by planting them alternately, so as to keep the wheat free from weeds.

Each row of allotments ought to be submitted to the following treatment:—

Nature of Manure.

1. Farmyard manure, 24 tons per acre.
2. " " 12 "
3. Normal stimulating manure. "
4. Normal manure.
5. Manure without nitrogen.
6. Manure without phosphate.
7. Manure without potash.
8. Manure without lime.
9. Manure without mineral matter.
10. No manure.

When the farm is on a somewhat large scale, it will be found advantageous to institute as an annex to the principal field of experiments a number of trial patches on a small scale scattered about indiscriminately. A few square yards of surface devoted to the growth of wheat or peas will generally be sufficient, and we shall soon see how the results gained by their use are to be interpreted. But if the soil on the experimental farm varies considerably, it is better to recur to the system of experiments that I have prescribed for elementary schools, but in this case plots of about four poles divided into four parts will be amply sufficient.

We will speak a little more in detail of these small fields for investigation, which may with justice be called the advanced sentinels of the principal experimental field.

<p>No. 1. Normal manure.</p>	<p>No. 2. Mineral manure.</p>
<p>No. 4. Soil without any manure,</p>	<p>No. 3. Nitrogenous manure.</p>

We have thus three combinations of manure, the effects of which are compared to the yields obtained on the soil without any manure.

- | | | |
|-------------------|--|------------------------|
| 1. No manure. | \| | 3. Mineral manure. |
| 2. Normal manure. | \| | 4. Nitrogenous manure. |

A few little corners of ground devoted to these investigations will not in any way disturb the rest of the work going on on the farm, and they make known the exact period at which the mineral or nitrogenous manures should be resorted to, whether they are used alone or associated with farmyard manure.

These small trial patches are, I repeat, like sentries placed in observation, and every intelligent grower, farmer, steward or proprietor ought constantly to consult them, as a captain at sea consults the barometer and the direction of the wind. But in order that these trials on a small scale may be of great utility, they must be begun a year before the systematic use of chemical manures to the whole farm; in this way their evidence is always a year in advance of the application on a large scale.

To those who may be rather alarmed at the prospect of such a number of trials, I can only point out the fact that wherever the use of chemical manure has been adopted these experimental plots are highly valued: the director likes to show them to his visitors; the employees of every grade make them the constant subject of discussion; and, finally, their indications always regulate the quantities of fertilising agents of which the manures are composed.

*Experimental Fields for Agricultural Colleges, Societies, and
Agricultural Committees.*

Here the end proposed is a higher one. If it concerns a school of agriculture, the pupils ought to find in it the elements of complete instruction, both theoretical and practical.

If the experimental field is under the control of a society or an agricultural committee, its object is not less important. It must enlighten practical men on the subject of the requirements of the land in that part of the country, and prove to them that all plants have not the same requirements, and that to obtain the best results from their farming operations they must vary the composition of the manures they use, not only as far as the nature of the component substance goes, but in the quantities employed.

One point on which the directors of schools ought especially to dwell is the contrast, or rather the opposition, which exists between leguminous plants and cereals, with respect to the action of nitrogenous matters. Whatever opinion may be held as to the form under which plants draw the nitrogen from the atmosphere, one fact stands prominently forward, *viz.*, that the nitrogenous matters, ammoniacal sulphates and sodic nitrate have little action on the leguminosæ, whilst they are the essential elements of the growth of wheat, beetroot and hemp, to mention only the principal crops in which nitrogenous matter is the dominant component. However much opposition there may be, the fact of this contrast between the various crops still remains, and foolish indeed would be the man who gave ammoniac sulphate to lucern or trefoil, and a mixture of lime and potassic chloride to wheat.

In both cases the result would be nugatory; but by reversing the use of the same agents, giving ammoniac sulphate to wheat, and lime and potash to lucern, abundant yields will be obtained.

Further, if the experiments are extended over a greater number of plants, the effects produced by the nitrogenous matter may be thus classified:—

Action of Nitrogenous Matter.

Wheat	very favourable
Potatoes	less favourable
Peas	little effect
Trefoil	„

Who would think that the nitrogen of trefoil has for its origin the nitrogenous compounds, whose action in certain cases is productive of harm when given to the soil? ¹

	Mineral manure without nitrogen lbs. per acre	Mineral manure with nitrogen lbs. per acre
1849	8,470	8,404
1850	2,068	2,115
1851	4,728	3,178

¹ In support of this opinion I refer my readers to the experiments performed by Messrs. Lawes and Gilbert on clover, in which nitrogenous matter proves hurtful.

I do not, therefore, hesitate to prescribe for schools and stations fields containing forty allotments of about four perches each, arranged in four rows of ten plots each.

The four most suitable crops are :—

Wheat		Potatoes
Beetroot		Peas

In order that the indications of the experimental field should correspond more closely than those of practice, I propose that wheat and peas should be alternated with beetroot and potatoes.

By the systematic use of experimental fields, practical men may be certain that they will learn more of the true principles of agricultural production than can be gathered from any books ; and when they have adopted the system, and Governments have been induced to do the same, they will acknowledge that agriculture ceases to be an art given over to the uncertainties of empiricism, but is raised to the rank of a true science, whose theoretical principles answer all the requirements of practice. The more I prosecute these studies the more I am convinced that a complete revolution in the traditions that the practical agriculture of the past has handed down to us is on the eve of being accomplished ; and this revolution we ought to forward with all our might, since it is destined to secure profit to private individuals and prosperity to the State by providing a large class of our fellow-subjects who live by manual labour with a more wholesome subsistence upon less onerous terms.

COMPOSITION OF THE MANURES TO BE USED IN THE EXPERIMENTAL FIELDS.

Manures for Wheat.

PLOT No. 1.		Tons per acre
Farmyard manure	. . . . .	60
PLOT No. 2.		
Farmyard manure	. . . . .	30
PLOT No. 3.		lbs. per acre
Normal stimulating manure, No. 1		
Calcic superphosphate	. . . . .	352
Potassic sulphate, at 80°	. . . . .	176
Ammonic sulphate	. . . . .	422
PLOT No. 4.		
Normal manure, No. 1		
Calcic superphosphate	. . . . .	352
Potassic sulphate, at 80°	. . . . .	176
Ammonic sulphate	. . . . .	343
PLOT No. 5.		
Manure without nitrogen		
Calcic superphosphate	. . . . .	352
Potassic sulphate, at 80°	. . . . .	176

PLOT No. 6.

	lbs. per acre
Manure without phosphates	
Potassic sulphate, at 80° . . .	176
Ammonic sulphate	343

PLOT No. 7.

Manure without potash	
Calcic superphosphate	352
Ammonic sulphate	343

PLOT No. 8.

Manure without mineral matter	
Ammonic sulphate	343

PLOT No. 9.

No manure at all.

Manures for Beetroot.

PLOT No. 1.

	Tons per acre
Farmyard manure	60

PLOT No. 2.

Farmyard manure	30
---------------------------	----

PLOT No. 3.

	lbs. per acre
Normal stimulating manure, No. 2	
Calcic superphosphate	352
Potassic sulphate, at 80° . . .	88
Ammonic sulphate	176
Sodic nitrate	224

PLOT No. 4.

Normal manure, No. 2	
Calcic superphosphate	352
Potassic sulphate, at 80° . . .	176
Ammonic sulphate	123
Sodic nitrate	224

PLOT No. 5.

Manure without nitrogenous matter	
Calcic superphosphate	352
Potassic sulphate, at 80° . . .	176

PLOT No. 6.

Manure without phosphates	
Potassic sulphate, at 80° . . .	176
Ammonic sulphate	123
Sodic nitrate	224

PLOT No. 7.

Manure without potash	lbs. per acre
Calcic superphosphate	352
Ammonic sulphate	123
Sodic nitrate	224

PLOT No. 8.

Manure without mineral matter	
Sodic nitrate	224
Ammonic sulphate	123

PLOT No. 9.

No manure at all.

Manures for Potatoes.

PLOT No. 1.

Farmyard manure	Tons per acre
	60

PLOT No. 2.

Farmyard manure	30
-------------------------	----

PLOT No. 3.

Normal stimulating manure, No. 3	lbs. per acre
Calcic superphosphate	352
Potassic sulphate	168
Sodic nitrate	224

PLOT No. 4.

Normal manure, No. 3	
Calcic superphosphate	352
Sodium nitrate	264
Potassium sulphate	168

PLOT No. 5.

Manure without nitrogen	
Calcic superphosphate	352
Potassium sulphate	168

PLOT No. 6.

Manure without phosphates	
Sodium nitrate	264
Potassium sulphate	168

PLOT No. 7.

Manure without potash	
Calcic superphosphate	352
Sodic nitrate	224

PLOT No. 8.

Manure without mineral matter	
Sodic nitrate	224

V.

TABLES FOR CALCULATING THE RELATIVE EXHAUSTION OF THE SOIL BY THE CULTIVATION OF DIFFERENT CROPS AND THE ALIMENTARY VALUE OF DIFFERENT KINDS OF FODDER PLANTS.

Use of the Tables.

AT the end of my lectures delivered in 1867, I gave a table showing the relative exhaustion of the soil under different crops, which I have now greatly extended by adding to it the researches of Wolff and Kühn.

Wolff's table, like mine of 1867, gives the quantity of phosphoric acid, potash, lime and nitrogen contained in the generality of crops. I have only made a single change in this table. I have substituted the proportions obtained in my own laboratory for those given by Wolff and Kühn, and as an addition to this information I have added the proportion of elementary principles of the same products, such as the protein, fatty matter, carbohydrates and salts contained in them, to show which relate only to their fertilising nature.

As regards the fertilising constituents, nitrogen, phosphoric acid, potash and lime, the information given in the table has an absolute value. It is true, however, that the composition of plants varies in a certain degree with the kind of soil in which they are grown, but these variations have but little value as far as the interests of agriculture are concerned.

As regards the alimentary compounds, we must use the tables with great judgment, and in order that they should be really useful and worthy of acceptance we should only compare together those products which are related to each other, such as straw with straw, dry fodder with green fodder, roots with roots, and grain with grain.

COMPOSITION OF THE PRINCIPAL AGRICULTURAL PLANTS.

Plants and other substances	Parts in a Thousand					Authorities	Parts in a Thousand					Authorities
	Water	Nitro- gen	Phos- phoric acid	Potash	Lime		Protein, etc.	Fat, etc.	Non- azotised extractive matter	Woody fibres	Salts	
I. DRY FODDER.												
Meadow hay . . .	144.00	13.10	4.10	17.10	7.70	Wolff	85.00	30.00	383.00	293.00	66.00	Kühn
Red clover . . .	210.00	16.60	3.90	16.40	15.15	Boussingault	134.00	32.00	285.00	330.00	56.00	"
White clover . . .	160.00	23.80	8.50	10.60	19.40	Wolff	149.00	35.00	339.00	250.00	60.00	"
Hybrid " . . .	160.00	24.50	4.70	15.70	14.80	"	153.00	33.00	259.00	305.00	83.00	"
Lucern . . .	123.09	32.33	7.40	31.28	25.01	G. Ville	144.00	28.00	257.00	347.00	60.00	"
Sainfoin . . .	160.00	21.30	4.70	17.90	14.60	Wolff	—	—	—	—	—	No analysis
Tares . . .	160.00	22.70	9.40	30.90	19.30	"	—	—	—	—	—	"
II. GREEN FODDER.												
Meadow grass in flower . . .	700.00	4.40	1.50	6.00	2.70	"	31.00	8.00	121.00	100.00	20.00	Kühn
Young grass . . .	800.00	5.00	2.20	11.60	2.20	"	—	—	—	—	—	No analysis
Rye " . . .	700.00	5.70	1.70	5.30	1.60	"	—	—	—	—	—	Kühn
Green rye . . .	700.00	4.30	2.40	6.30	1.20	"	33.00	7.50	104.00	79.00	16.00	"
" maize . . .	862.00	3.20	0.70	2.90	1.20	"	12.00	5.00	103.00	47.00	11.00	"
Buckwheat . . .	826.00	5.10	1.10	4.30	6.60	"	24.00	6.00	63.00	43.00	14.00	"
Red clover . . .	800.00	5.30	1.30	4.60	4.60	"	37.00	8.00	83.00	66.00	16.00	"
White clover . . .	810.00	5.60	2.00	2.40	4.40	"	40.00	8.50	80.00	56.00	14.00	"
Hybrid " . . .	815.00	5.30	1.00	3.50	3.20	"	33.00	6.50	65.00	65.00	10.00	"
Lucern . . .	753.00	7.20	1.50	4.50	8.50	"	45.00	7.00	84.00	93.00	18.00	"
Sainfoin . . .	785.00	5.10	1.20	4.60	3.70	"	—	—	—	—	—	No analysis
Tares . . .	820.00	4.80	2.00	6.60	4.10	"	37.00	6.00	61.00	60.00	16.00	Kühn
Peas . . .	815.00	5.00	1.80	5.60	3.90	"	35.00	6.00	76.00	54.00	14.00	"
Colza . . .	850.00	5.10	1.20	4.40	3.10	"	29.00	6.00	37.00	42.00	16.00	"

AGRICULTURAL PLANTS—continued.

Plants and other substances	Parts in a Thousand					Authorities	Parts in a Thousand					Authorities
	Water	Nitro- gen	Phos- phoric acid	Potash	Lime		Protein, etc.	Fat, etc.	Non- azotised extractive matter	Woody fibres	Salts	
STRAW, ETC.—continued.												
Spelt-wheat straw . . .	143.00	3.20	3.00	5.30	2.30	Wolf	20.00	15.00	287.00	480.00	55.00	Kühn
Barley straw . . .	132.50	7.17	1.48	11.56	6.60	G. Ville	30.00	14.00	313.00	456.00	44.00	"
Oat " . . .	287.00	2.85	1.10	8.80	3.00	Boussingault	25.00	20.00	356.00	412.00	44.00	"
Maize " . . .	140.00	4.80	3.80	16.60	5.00	Wolf	30.00	11.00	379.00	400.00	40.00	"
Pea haulm . . .	135.50	15.39	4.05	8.24	28.06	G. Ville	73.00	20.00	325.00	392.00	49.00	"
Haricot haulm . . .	203.20	26.60	4.50	8.24	28.06	"	—	—	—	—	—	No analysis
Horsebean haulm . . .	180.00	16.30	4.10	25.90	13.50	Wolf	—	—	—	—	—	"
Buckwheat . . .	160.00	13.00	6.10	24.10	9.50	G. Ville	39.00	15.00	332.00	400.00	53.00	Kühn
Colza haulm . . .	136.25	10.40	1.54	3.21	9.55	Wolf	—	—	—	—	—	No analysis
Poppy " . . .	160.00	—	2.30	25.10	19.90	G. Ville	—	—	—	—	—	Kühn
Wheat chaff (March) . . .	148.00	9.07	2.50	4.19	5.40	"	45.00	15.00	320.00	357.00	120.00	No analysis
" " (winter) . . .	105.60	10.12	1.89	1.42	1.95	"	—	—	—	—	—	Kühn
Barley " . . .	130.83	10.06	2.70	9.96	9.60	Wolf	—	—	—	—	—	No analysis
Oat " . . .	143.00	6.40	0.20	10.40	7.00	"	40.00	15.00	282.00	340.00	180.00	Kühn
Bean shells . . .	185.04	14.80	5.50	13.79	2.17	G. Ville	—	—	—	—	—	No analysis
Spelt-wheat chaff . . .	130.00	4.60	6.00	7.90	2.00	Wolf	29.00	13.00	315.00	415.00	85.00	Kühn
Pea shells . . .	166.50	13.62	5.50	13.79	2.17	G. Ville	81.00	15.00	333.00	368.00	60.00	"
Barley chaff . . .	140.00	4.80	2.40	9.40	12.70	Wolf	—	—	—	—	—	No analysis
Maize shucks . . .	115.00	2.30	0.20	2.40	0.20	"	14.00	14.00	426.00	378.00	28.00	Kühn
Flax chaff . . .	120.00	—	1.60	18.10	17.20	"	—	—	—	—	—	No analysis
Colza " . . .	149.50	11.04	2.08	31.91	31.15	G. Ville	40.00	18.00	426.00	354.00	60.00	Kühn

VII. PLANTS USED IN
MANUFACTURES.

Flax stems . . .	140.00	4.30	11.80	8.30	Wolf	—	—	—	No analysis
Beaten flax . . .	100.00	1.30	1.90	11.10	Kühn	—	—	—	"
Spun . . .	100.00	0.70	0.20	3.80	"	—	—	—	"
Flax plant (entire) . . .	250.00	7.40	11.30	5.00	"	—	—	—	"
Hemp . . .	300.00	3.30	5.20	12.20	"	—	—	—	"
Hop . . .	250.00	9.00	19.40	11.80	"	—	—	—	"
Hops (flowers) . . .	120.00	9.00	22.30	10.10	"	—	—	—	"
Tobacco . . .	180.00	7.10	54.10	73.10	"	—	—	—	"

VIII. VARIOUS LITERS.

Furze . . .	200.00	1.80	4.80	6.80	Wolf	37.00	30.00	153.00	197.00	37.00	Kühn
Fern . . .	160.00	5.70	25.20	8.30	"	—	—	—	—	—	No analysis
Broom . . .	160.00	1.60	6.90	3.20	"	—	—	—	—	—	"
Horse tail . . .	140.00	4.10	27.00	25.60	"	—	—	—	—	—	"
Sea wrack . . .	180.00	3.70	17.10	16.40	"	—	—	—	—	—	"
Beech leaves (autumn) . . .	150.00	2.40	3.00	25.80	"	—	—	—	—	—	"
Oak leaves . . .	150.00	3.40	1.50	20.20	"	—	—	—	—	—	"
Fresh pine needles . . .	475.00	2.00	0.80	3.40	"	25.00	37.00	225.00	119.00	9.00	Kühn
Reed . . .	180.00	0.80	3.30	2.30	"	—	—	—	—	—	No analysis
Carex . . .	140.00	4.70	23.10	3.70	"	—	—	—	—	—	"
Rush . . .	140.00	2.90	10.70	4.30	"	—	—	—	—	—	"

IX. GRAINS AND SEEDS.

Wheat (March) . . .	147.50	23.62	8.93	6.03	0.57	G. Ville	132.00	16.00	662.00	30.00	17.00	Kühn
" (winter) . . .	154.00	28.29	6.80	5.02	0.51	"	110.00	20.00	672.00	37.00	18.00	"
Rye . . .	149.00	17.60	8.20	5.40	0.50	Wolf	100.00	23.00	641.00	71.00	22.00	"
Barley . . .	154.25	20.59	9.49	7.27	0.77	G. Ville	120.00	60.00	566.00	90.00	27.00	"
Oats . . .	208.00	17.50	4.75	4.10	1.20	Boussingault	120.00	60.00	566.00	90.00	27.00	"

AGRICULTURAL PLANTS—continued.

Plants and other substances	Parts in a Thousand					Authorities	Parts in a Thousand					Authorities
	Water	Nitro- gen	Phos- phoric acid	Potash	Lime		Protein, etc.	Fat, etc.	Non- aroidised extractive matter	Woody fibres	Salts	
GRAINS AND SEEDS-- <i>contd.</i>												
Spelt-wheat . . .	148.00	16.00	7.20	6.20	0.90	Wolff	100.00	14.00	528.00	170.00	38.00	Kühn
Maize . . .	136.00	16.00	5.50	3.30	0.30	"	106.00	68.00	610.00	76.00	13.00	"
Millet . . .	130.00	24.00	9.10	4.70	0.40	"	127.00	33.00	580.00	95.00	30.00	"
Sorgho . . .	140.00	—	8.10	4.20	0.20	"	—	—	—	—	—	No analysis
Buckwheat . . .	141.00	14.40	4.40	2.10	0.30	"	78.00	15.00	581.00	176.00	18.00	Kühn
Colza . . .	81.50	41.89	12.86	7.13	3.25	G. Ville	194.00	425.00	104.00	100.00	39.00	"
Linseed . . .	118.00	32.00	13.00	10.40	2.70	Wolff	—	—	—	—	—	No analysis
Haricots . . .	170.01	53.90	12.55	12.26	0.90	G. Ville	—	—	—	—	—	"
Peas . . .	191.00	42.58	12.55	12.26	0.90	"	224.00	30.00	526.00	64.00	24.00	Kühn
Hempseed . . .	122.00	26.20	17.50	9.70	11.30	Wolff	163.00	336.00	216.00	121.00	42.00	"
Poppyseed . . .	147.00	28.00	16.40	7.10	18.50	"	175.00	410.00	137.00	61.00	70.00	"
Swedes . . .	140.00	—	7.60	9.10	7.60	"	—	—	—	—	—	No analysis
Sugar beet . . .	146.00	—	7.50	11.10	10.40	"	—	—	—	—	—	"
Turnips . . .	120.00	—	14.10	7.70	6.10	"	—	—	—	—	—	"
Carrots . . .	120.00	—	11.80	14.30	29.00	"	—	—	—	—	—	"
Tares . . .	136.00	44.00	7.90	6.30	0.60	"	275.00	19.00	491.00	56.00	23.0	Kühn
Horsebeans . . .	141.00	40.80	11.60	12.00	1.50	"	251.00	16.00	445.00	117.00	30.0	"
Lentils . . .	134.00	38.10	5.20	7.70	0.90	"	—	—	—	—	—	No analysis
Lupins . . .	138.00	55.20	8.70	11.40	2.70	"	—	—	—	—	—	"
Clover . . .	150.00	—	12.40	13.80	2.30	"	—	—	—	—	—	"
Sainfoin . . .	160.00	—	9.00	10.80	11.90	"	—	—	—	—	—	"
Beans . . .	—	—	—	—	—	Boussingault	251.00	16.00	445.00	117.00	30.00	Kühn

X. ANIMAL PRODUCTS.										Wolff				Kühn			
										1.50	1.70	4.00	36.00	47.00	7.00	No analysis	
Milk	.	.	.	874.00	6.40	1.90	1.70	1.50									
Veal.	.	.	.	780.00	34.90	5.80	4.10	0.20	"								
Beef.	.	.	.	770.00	36.00	4.30	5.20	0.20	"								
Pork	.	.	.	740.00	34.70	4.60	3.90	0.80	"								
Calf (the whole animal)	.	.	.	662.00	25.00	13.80	2.40	16.30	"								
Ox	.	.	.	597.00	26.60	18.60	1.70	20.80	"								
Sheep	.	.	.	591.00	22.40	12.30	1.50	13.20	"								
Pig	.	.	.	528.00	20.00	8.80	1.80	9.20	"								
Blood	.	.	.	790.00	32.00	0.40	0.60	0.10	"								
Washed wool	.	.	.	100.00	94.40	0.30	1.90	2.50	"								
Cheese	.	.	.	450.00	45.30	11.50	2.50	6.90	"								
Eggs.	.	.	.	672.00	21.80	3.20	1.60	43.30	"								
XI. MANURES.										Ville							
Stable dung	.	.	.	800.00	4.16	1.76	4.92	10.46									
Liquid muck	.	.	.	982.00	1.50	0.10	4.90	0.30	"								
Human feces (fresh)	.	.	.	772.00	10.00	10.90	2.50	6.20	"								
" urine	"	"	"	959.00	6.00	1.70	2.00	0.20	"								
The two mixed	"	"	"	935.00	7.00	2.60	2.10	0.90	"								
Night soil.	.	.	.	970.00	3.50	2.80	2.00	1.00	"								
Bone dust.	.	.	.	50.00	40.00	257.00	—	313.00	"								
Bone black	.	.	.	40.00	—	312.00	—	430.00	"								
Superphosphate	.	.	.	160.00	—	160.00	—	210.00	"								
Peruvian guano	.	.	.	140.00	125.00	137.00	16.00	121.00	"								
Baker's	.	.	.	40.00	10.00	405.00	2.00	434.00	"								
"	.	.	.	150.00	85.00	133.00	3.00	144.00	"								
Norway fish guano	.	.	.	20.00	150.00	—	—	1.00	"								
Chilian nitre	.	.	.	50.00	200.00	—	—	—	"								
Ammonic sulphate	.	.	.	33.00	—	—	—	12.00	"								
Pay salt	.	.	.	50.00	—	—	—	—	"								
Rough potassic sulphate	.	.	.	50.00	—	—	100.00	19.00	"								

If used with judgment, these tables are thoroughly trustworthy guides in practice. Where a farm is conducted on proper principles, the composition of the products of the soil and of the fodder given to the live stock should form the object of constant investigation. There is no denying the fact that plants and animals can only thrive upon fixed principles, so that to draw from them as much benefit as possible we must leave nothing to chance, and to this end we must continually refer to the above tables as the engineer refers to his agenda or the sailor to his Nautical Almanac.

VI.

COMPARATIVE ACTION OF THE DIFFERENT FERTILISING AGENTS ON THE GROWTH OF PLANTS.

(See Lecture XI., pp. 156-179.)

The Function of Potash in Vegetation.

I HAVE long since pointed out the impossibility of replacing potash by soda in the formulæ for artificial manures. I have proved by direct experiments on wheat (*Comptes Rendus*, 1860, vol. li., p. 437), that in the absence of potash this plant only gives precarious and uncertain results. The same thing has happened with regard to potatoes at Vincennes during the last twelve years. In the case of manures in which potash is wanted, the use of sodic nitrate produces no effect; but when it is associated with potash, sodic nitrate at once becomes valuable. By the help of the illustrations at page 338, where the size of each heap is in proportion to the weight of the crop, some idea of this contrast is obtained.

Another conclusion which we may draw from these experiments is no less important, namely, that potash ought to be the dominant constituent in manure for growing potatoes. Besides this, the lack of potash in the soil is coincident with the appearance of the potato disease, whence we may draw a second conclusion, that when plants are deprived of their dominant mineral constituent, and consequently of one of the most essential constituents of their existence, they become the prey of inferior organisms such as microscopic fungi, aphides, etc. We have here a startling and unexpected explanation of the cause of one of the most terrible plagues with which the farmer has to fight, namely, plant diseases. For many years past the same phenomena have been reproduced at Vincennes with invariable regularity. Until the end of the month of May, besides the very marked differences in the size of the plants in the different plots, nothing striking seems to indicate the great change which is on the point of taking place. This change first manifests itself about the middle of the month of June, and invariably begins with the plot which had received manure in which the potash has been suppressed, as well as in that which has received no manure at all. The plants in the plots which have been dressed with normal manure are

SERIES OF EXPERIMENTS MADE ON POTATOES IN 1869.

The heaps correspond to the weight of the different crops.

NORMAL MANURE.



YIELD PER ACRE.
6 tons 8 cwts.

MANURE WITHOUT NITROGENOUS
MATER.



YIELD PER ACRE.
4 tons 14 cwts.

WITHOUT PHOSPHATE.



YIELD PER ACRE.
6 tons.

WITHOUT POTASH.



YIELD PER ACRE.
3 tons 18 cwts.

WITHOUT LIME.



YIELD PER ACRE.
5 tons 8 cwts.

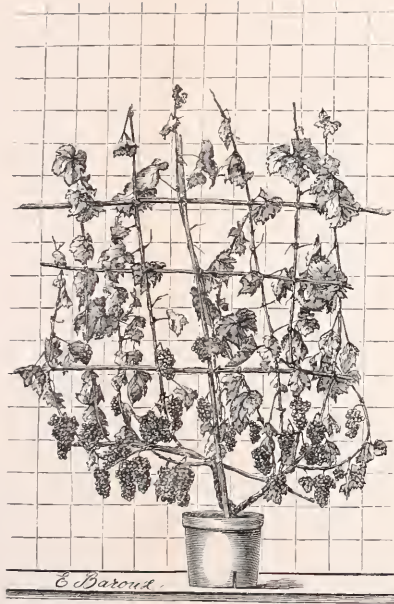
WITHOUT ANY MANURE.



YIELD PER ACRE.
1 ton 8 cwts.

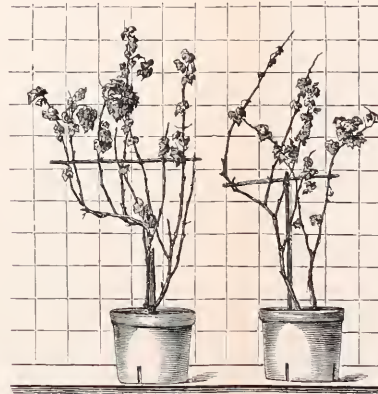
SERIES OF EXPERIMENTS MADE ON THE VINE IN 1875.

NORMAL MANURE.

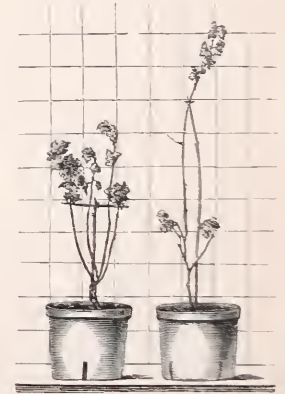


	YIELD PER ACRE.			REMARK.
	GRAPES. Tons, Cwts.	MUST. Gallons.	Percentage of Must.	
Normal manure	4 15	848	14·8	On the plot without any manure two vines gave only a few shrivelled grapes; in fact, the crop may be counted as nothing. These grapes gave 12 per cent. of glucose.
Manure without nitrogenous matter	2 10	442	16·4	
„ without phosphate	2 18	512	16·4	
„ without potash	—	—	—	
„ without lime	3 2	548	15·4	
Without manure	(See Remark.)			

MANURE WITHOUT POTASH.



WITHOUT ANY MANURE.



These vines, which represent the general average of those grown in each plot, were taken up and temporarily potted for being photographed.

luxuriantly green, but those in the plot which has received no potash, and in that which has received no manure at all, a number of copper-coloured spots begin to make their appearance, and shortly afterwards begin to spread very rapidly, gradually extending themselves over the whole of the foliage, and drying up the plant as if a burning wind had passed over it. As for the potatoes themselves they are hardly larger than walnuts, have a peculiarly disagreeable smell, and do not keep well.

With the normal manure the crop is from 8 tons to 10 tons 16 cwt. per acre, but by suppressing the potash it falls to 2 tons 16 cwt.

Until lately I always thought that the leguminosæ and the potato were the plants which showed a special preference for potash, but the vine distances them in this respect in a most surprising manner. In the case of the potato the suppression of potash manifests itself by a diminution of the crop; with the vine, however, little or no fruit makes its appearance, and we virtually get no crop at all. The vine itself barely sends forth two or three feeble shoots, and the few shrivelled leaves are hardly as large as a crown piece, whilst those of the plants which have been dressed with normal manure are as large as a man's hand. In the plot without potash, as early as the beginning of the month of June, the leaves first turn red and then black, drying up and shrivelling like those of the potatoes which have received the same treatment.

The following figures are instructive:—

CROP OF GRAPES.

	Per acre grapes	Must
Plot with normal manure .	4 tons 15 cwt.	848 gallons
Plot without potash .	0 „ 0 „	

Since I first began my experiments on plant growth I have met with nothing to be compared with this result, whether we consider the definiteness of the conclusions to be drawn from or the absolute exactitude of their indications.

THEORETICAL EXPERIMENTS ON THE GROWTH OF PLANTS IN CALCINED SAND, THE TEACHINGS OF WHICH HAVE BEEN CONFIRMED BY PRACTICAL RESULTS.

Soda cannot replace potash as a fertilising agent.

For many years past English agriculturists have consumed an immense and constantly increasing quantity of sodic nitrate, imported from Peru. This salt, the good effects of which have been abundantly confirmed by practice, was first brought into notice by the researches of M. Kuhlmann,¹ by the more theoretical

¹ *Expériences Chimiques et Agronomes*, 1847.

SERIES OF 1



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¹ *Expériences Chimiques et Agronomes*, 1847.

experiments of MM. Bineau, Boussingault and myself, and by the numerous and remarkable papers published by E. B. Pusey, in the *Journal of the Royal Agricultural Society*, vols. xiii., xiv. and xv.

Whether chemists or farmers, theoretical or practical men, all are at the present agreed on reckoning sodic nitrate amongst the most valuable agents for fertilising the soil.

Before Leblanc discovered the admirable process which enables the manufacturer to transform sea-salt into soda, advantage was taken of the power possessed by certain maritime plants of extracting soda from sea-water, and of storing it up in their frail tissues. On burning these plants they leave behind them a residue in the form of an ash, the principal constituent of which is sodic carbonate. In fact, in former days a similar practice was followed with regard to maritime plants to that which now obtains in America, where, as soon as the means of communication and transport allow of it, the forests are made to yield a supply of potash, the trees being burnt in the same way as the maritime plants, in order to make them give up the potash which they have assimilated during vegetation.

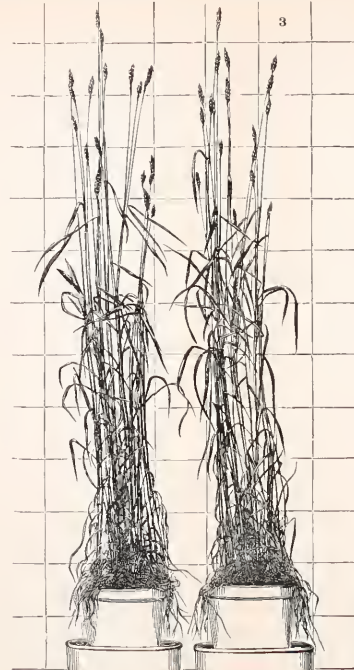
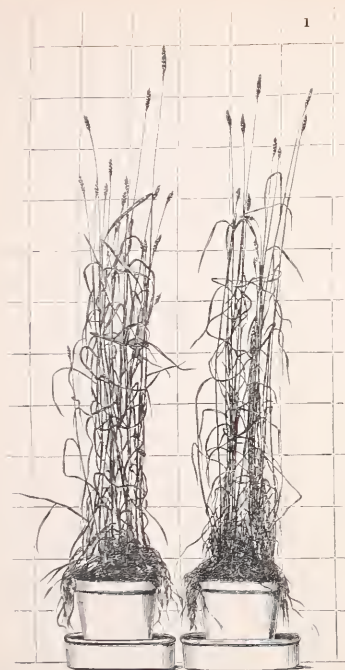
Amongst the plants most fitted for the extraction of soda is the barilla, which is cultivated on the coasts of Spain, which, when burnt, gives an ash capable of yielding salts which contain from 20 to 40 per cent. of sodic carbonate.¹ Although less rich in alkalies, the ashes of seaweed still contain considerable quantities of potash and soda salts. The abundance of soda in the ash of these plants, taken in connection with the fact of their disappearance at a certain distance from the coast where the soil no longer contains salt, clearly indicates that soda is essential to them, and that it fulfils a primary function with regard to their growth. In consequence of the close chemical relationship existing between potash and soda, it became an interesting question to discover up to what point the two alkalies would replace each other, and whether this substitution in any way interfered with the natural course of their vegetable life. M. Payen states that the stems and leaves of the *Mesembrianthemum crystallinum*, which is used in the island of Teneriffe for the extraction of soda, are covered with glands, filled with a solution of soda oxalate, which disappears, and gives place to potassic oxalate in proportion as the place of its growth becomes removed from the vicinity of the seashore.

The venerable M. de Gasparin mentions another plant in which the substitution of potash for soda takes place still more completely without any evil effects. It seems that the *Salsola tragus*, which is used as a source of soda between Frontignan and Aigues Mortes, is found far up the valley of the Rhone. It has just as vigorous an appearance when growing in the most inland locality as on the seashore, and that, too, in spite of its containing nothing but potash, the soda having entirely disappeared.² It would seem to result

¹Thenard, *Chimie*, iii., p. 141.

²De Gasparin, *Cours d'Agriculture*, 3rd edition, vol. i., p. 146.

THEORETICAL EXPERIMENTS ON THE GROWTH OF PLANTS IN CALCINED SAND.



All the pots were dressed with *Barilla* manure, minus the two alkalis, potash and soda. These were afterwards added, alone or mixed, under two different conditions, as nitrates used alone, or as nitrates mixed with potassic silicate.

No. 1. POTASSIC NITRATE.

	Gr.
Straw	188
Grain	43
	<hr/> 231

No. 2 SODIC NITRATE.

	Gr.
Straw	110
Grain	5
	<hr/> 115

No. 3. POTASSIC NITRATE, POTASSIC SILICATE.

	Gr.
Straw	269
Grain	77
	<hr/> 346

No. 4. POTASSIC NITRATE, SODIC NITRATE, POTASSIC SILICATE.

	Gr.
Straw	243
Grain	72
	<hr/> 315

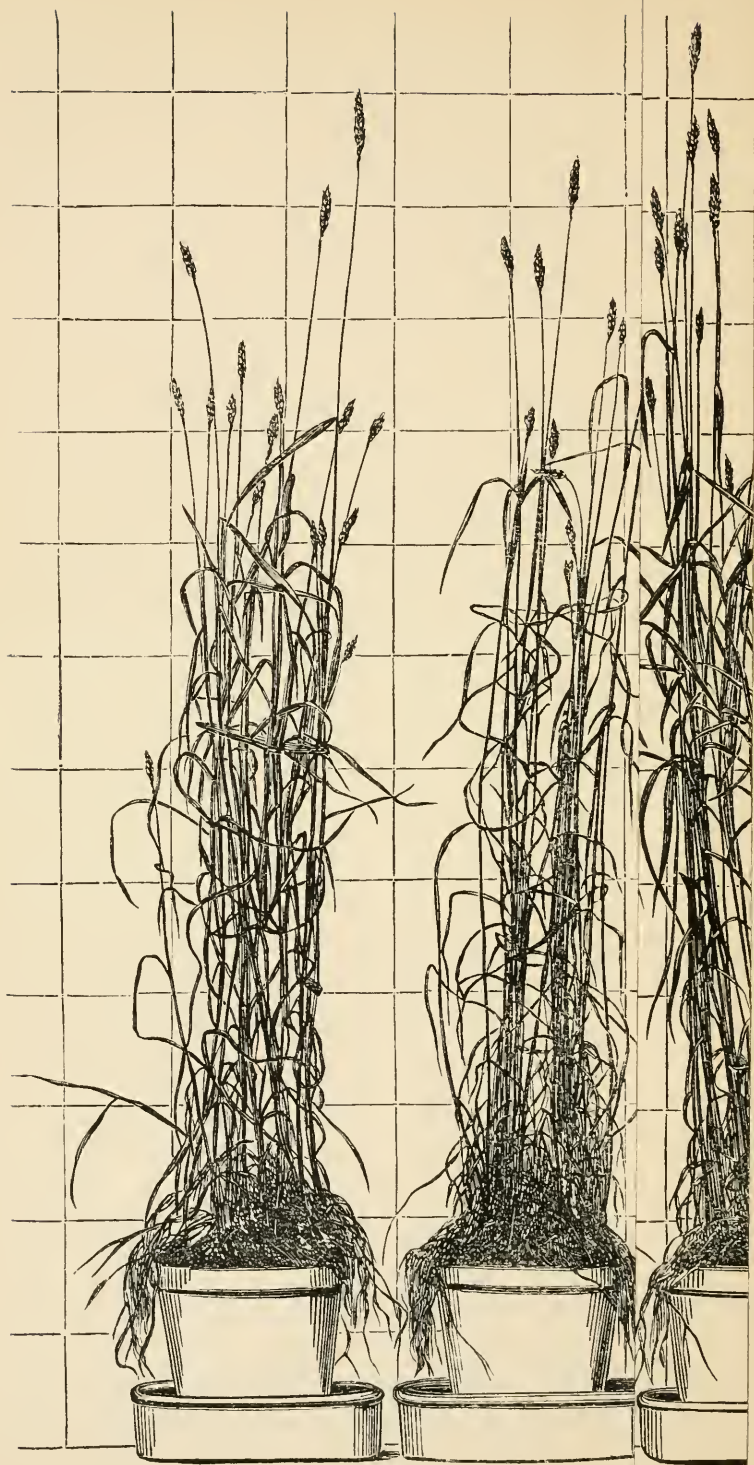
from those two examples that potash is sometimes capable of replacing soda, but it remained to be determined whether the converse would hold good, that is to say, whether soda could be substituted for potash in certain plants, and whether they would suffer by such substitution. With respect to corn I have no hesitation in saying at once that the use of soda, to the exclusion of potash, seriously interferes with the growth of the plant, the crop falling to three-quarters. For this purpose I invoke the testimony of two experiments executed under widely different conditions, the results of which verify and complete each other. For the reasons given in my paper published in the *Comptes Rendus*, of the Academy of Sciences, vol. li., I selected for my experiments some soil from the Landes which is naturally destitute of potash, each pot receiving 155 grains of calcic phosphate and $1\frac{3}{4}$ grains of nitrogen. The potash and the soda were used in the state of nitrate. With the calcic phosphate and the potassic nitrate the plants grew and flourished. Under these conditions the wheat succeeded admirably. The straw was firm, the ears well formed and laden with grain which was heavy and plentiful. But let the potassic nitrate be replaced by sodic nitrate, the character of the vegetation is changed immediately. The wheat grows badly, and instead of springing up vertically, grows in all manner of ways. The ears are few in number, and the grain small in amount and size, and imperfect in form.

I laid before the Academy photographs of these two experiments, as well as the weight of the crops obtained.

Experiments on wheat grown in soil from the Landes, the gatherings being dried at 212° F. Twenty wheat grains were sown in each case.

Calcic phosphate Potassic nitrate			Calcic phosphate Sodic nitrate		
		grains			grains
Straw and roots	.	188	Straw and roots	.	110
160 wheat grains	.	43	20 wheat grains	.	5
		<hr/> 231			<hr/> 115

In fact the difference is just double. Soda, therefore, cannot, in this case at any rate, replace potash. I have already said that this proportion would admit of another mode of proof, which is as follows: Instead of adding to the soil from the Landes a mixture of calcic phosphate and potassic nitrate, or of calcic phosphate and sodic nitrate only, we add to each of these mixtures 62 grains of potassic silicate. In the absence of the silicate the plants grown by the aid of the sodic nitrate were inferior to those grown with the potassic nitrate. But the addition of the silicate equalises the results at once, and the sodic nitrate is now apparently equal in its effects to the potassic nitrate. Why, it may be asked, do the two



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In fact the difference is just double. Soda, therefore, cannot, in this case at any rate, replace potash. I have already said that this proportion would admit of another mode of proof, which is as follows: Instead of adding to the soil from the Landes a mixture of calcic phosphate and potassic nitrate, or of calcic phosphate and sodic nitrate only, we add to each of these mixtures 62 grains of potassic silicate. In the absence of the silicate the plants grown by the aid of the sodic nitrate were inferior to those grown with the potassic nitrate. But the addition of the silicate equalises the results at once, and the sodic nitrate is now apparently equal in its effects to the potassic nitrate. Why, it may be asked, do the two

nitrate now produce the same effect? Simply because they only act by their nitrogen. The mould being fully provided with potash by the addition of a silicate, the potash of the nitre exerts no influence whatever. A few more figures will help me to put the matter in a more precise way.

Experiments on wheat grown in soil from the Landes, the gatherings being dried at 212° F. Twenty wheat grains were sown in each case.

Calcic phosphate Potassic nitrate Potassic silicate			Calcic phosphate Sodic nitrate Potassic silicate		
Straw and roots	.	grains 269	Straw and roots	.	grains 243
211 wheat grains	.	77	210 wheat grains	.	72
<hr/> 346			<hr/> 315		

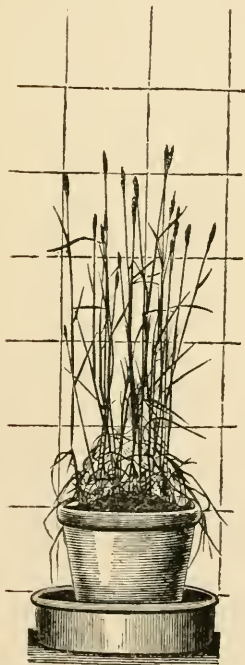
The conclusion to be drawn from these experiments is that as far as wheat is concerned soda cannot replace potash; sodic nitrate, therefore, when used in conjunction with calcic phosphate, is but a poor manure, but by the addition of potash we at once raise the value of the mixture as a fertilising agent.

The above are average results. The following are the experiments from which these average results were deduced:—

Calcic phosphate Potassic nitrate Potassic silicate			Calcic phosphate Sodic nitrate Potassic silicate		
I.			I.		
Straw and roots	.	grains 274	Straw and roots	.	grains 236
215 wheat grains	.	83	220 wheat grains	.	69
<hr/> 357			<hr/> 305		
II.			II.		
Straw and roots	.	grains 264	Straw and roots	.	grains 250
207 wheat grains	.	72	201 wheat grains	.	76
<hr/> 336			<hr/> 326		

58.
D SAND.

1860.
SAND HUMUS.



Grains	
ts . .	76
. . .	2
	<hr/> 78

Grains	
Straw and roots . .	81
Seeds	4
	<hr/> 85

COMPARATIVE ACTION OF CONSTITUENTS OF PLANT PRODUCTION.

EXPERIMENTAL CULTIVATION IN CALCINED SAND.

STIMULATING CULTIVATION.

ACTIVE CULTIVATION.

This series of experiments was made in unglazed porcelain pots which had been previously soaked in melted wax in order to protect plants from the saline exudations which form on ordinary clay pots. Under these conditions the growth is not so active and the yield is less; but the results are more exact, better defined, and more fitted to elucidate the laws of vegetation which are the safest guide upon which practice can rely.



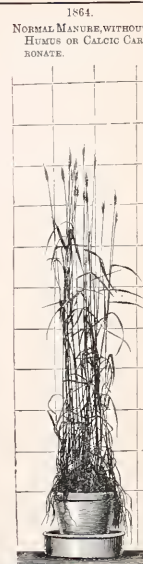
1860.	
NORMAL MANURE.	
HUMUS OR CALCIC CARBONATE.	
Straw and roots . .	346
270 seeds	134
	480



1860.	
NORMAL MANURE.	
CALCID CARBONATE.	
Straw and roots . .	239
127 seeds	62
	301



1864.	
NORMAL MANURE AND HUMUS.	
Straw and roots . .	221
163 seeds	53
	274



1864.	
NORMAL MANURE, WITHOUT HUMUS OR CALCIC CARBONATE.	
Straw and roots . .	255
137 seeds	66
	321



1858.	
NITROGENOUS MATTER ONLY, WITHOUT MINERAL MATTER.	
Straw and roots . .	146
6 seeds	1
	147



1858.	
MINERAL MATTER ONLY, WITHOUT NITROGENOUS MATTER.	
Straw and roots . .	98
23 seeds	8
	106



1859.	
NORMAL MANURE WITHOUT POTASH.	
Straw and roots . .	90
15 seeds	3
	93



1864.	
NORMAL MANURE WITHOUT MAGNESIA.	
Straw and roots . .	86.0
Seeds	00.6
	86.6



1860.	
NORMAL MANURE WITHOUT PHOSPHATE.	
Straw and roots . .	9



1858.	
CALCID SAND.	
Straw and roots . .	76
Seeds	2
	78



1860.	
SAND HUMUS.	
Straw and roots . .	81
Seeds	4
	85

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